THE UNITY

OF

THE PHYSICAL SCIENCES.

THE UNITY

OF

THE PHYSICAL SCIENCES:

BEING

AN INQUIRY

INTO THE CAUSES OF GRAVITATION AND POLARITY,

WITH

AN APPLICATION

OF THE RESULTS TO SOME OF THE PRINCIPAL PHÆNOMENA
IN EACH OF THE PHYSICAL SCIENCES.

BY

JOHN DICKSON.

LONDON:
JOHN VAN VOORST, PATERNOSTER ROW.
MDCCCLIX.

PRINTED BY TAYLOR AND FRANCIS,
RED LION COURT, FLEET STREET.

PREFACE.

Being strongly impressed with a belief in the idea, that if there really be an elastic ether or medium pervading space, it must be necessary in tracing the effects of its action to take into account not only the force or motion proceeding from the atoms of matter, but also that force which must act from without, maintaining, or restoring when disturbed, the equilibrium of the medium, I endeavoured to trace the consequences of such an action, and was thus led to a series of results very singularly accordant with many of the principal phænomena in every department of Natural Philosophy, whilst, the longer I studied the subject, and the more familiar I became with its action, the wider grew the field of application, and the more perfect and minute became the accordance of fact with theory. In the following pages will be found an account of the results obtained, and the reasoning which led to them. I have drawn it up as simply and concisely as I could, my object being, by putting the points at issue plainly and clearly before my readers, to obtain an answer to the question—Are these results correctly deduced from the premises or

not?—or, rather, are the results which are correctly deduced sufficient in number and importance to warrant the belief that in such an action of the particles of a medium we have the common origin of all the varied phænomena of the Physical Sciences, and the true interpretation of that dream regarding the Unity of Matter which has haunted so many minds?

CONTENTS.

CHAPTER I.

ON THE ACTION OF A MEDIUM, AND DEFINITIONS.

CHAPTER II.

ON GRAVITATION.

CHAPTER III.

ON POLARITY.

CHAPTER IV.

ON LIGHT, HEAT, AND THE PLANETARY MOTIONS.

CHAPTER V.

ON ELECTRICITY, ELECTRIC CURRENTS, AND MAGNETISM.

CHAPTER VI.

CONCLUDING REMARKS.

THE UNITY

OF

THE PHYSICAL SCIENCES.

CHAPTER I.

ON THE ACTION OF A MEDIUM, AND DEFINITIONS.

1. It is now a very generally received opinion that the space which separates the different masses of matter in the universe, as well as the constituent atoms of such masses, is not an absolute void, but is occupied by a perfectly elastic fluid or medium of great rarity; and that many, if not all, the phænomena of nature are caused by vibrating motions impressed on the particles of this medium.

But it is to be observed that the real question at issue between the supporters of the theory of a medium and that of emission is not, as it is often put, whether all space is filled by minute particles of matter or not, but whether these particles move only *from* the different atoms of matter as centres, or move both from and to these centres; for, that all space is occupied by particles of matter is a conclusion arising equally from the theory of emission as from that of a medium. Thus, supposing light, gravity, &c. to consist of particles emanating from the sun and planets (whether only of one or more descriptions is not at present material), then, whatever be the distance from the sun which these particles have reached, the

intermediate space must at all points be occupied by such, their emission being constant. At first sight it may appear the more simple view to consider the particles as moving only in one direction, but it is in reality the more complex; for it is then necessary not only to account for the constant production of force or motion, but also for the constant production of matter: whereas, on the hypothesis of a medium, it is only necessary to account for the constant production of motion—a problem which I believe to admit of a very simple solution.

2. The subject naturally divides itself into two inquiries. The first—as to the possibility of the existence of such a medium: What peculiar qualities must its particles possess to render its existence and the perpetuance of its action possible or probable?

The second: Supposing that such a medium exists, can it be demonstrated that the results of its action coincide with the known facts of gravity, polarity, and the other phænomena of nature?

It is, I think, of the greatest importance that these two branches of the subject should be kept perfectly distinct, and therefore the present inquiry is limited to an attempt at demonstrating that the effects of these two motions of the particles of a medium must produce results coinciding with the known facts of gravity and polarity, and to an application of these results to the explanation of some of the principal phænomena of light, heat, electricity, and magnetism.

3. Let it be granted that the particles of the medium possess no property except that of elasticity,—that is the property of repelling each other; but that the space through which the particles can so act is limited,—that is, when the distance between two particles exceeds a certain amount, these two particles can have no action on each other.

4. When motion is impressed on the particles of this medium in every direction outwards from a centre, then, so long as the force impinging on a point is inversely as the square of the distance of that point from the centre, the total force moving

outwards must remain unchanged, being merely diffused through a greater space as the distance from the centre increases; therefore, so long as the force obeys this law, no recoil or return force can be generated causing the particles of the medium to return to their former position; for, if there were, the total force moving outwards would be decreased thereby.

Beyond the limits within which the force obeys this law, there must therefore be a space in which the force obeys another law, and in which the recoil or return force is generated; for if there is no return force there can be no medium.

5. At the greatest distance, however, to which observation has yet extended, all the forces which emanate from the atoms of matter have been found to obey this law; hence the distance from the centre at which this return force is generated must be immeasurably great. The motion of the particles of the medium cannot then be considered as a progressive vibratory motion; that is, if A, B, C, be consecutive particles, A cannot be considered as first moving from and to the centre, then B, then C; but precisely as A must have been in motion *from* the centre, before B could commence to move in that direction, so must B have been in motion *to* the centre before A could return to it. Thus, although the one force may be a consequence of the other, yet, practically speaking, they are independent forces, the cessation of the one not involving the immediate cessation of the other. Thus, supposing that in the space beyond an interposing body all force moving outward has ceased, yet, in this space, the force moving inward may not have ceased.

6. These two forces being equal, whatever effect the force moving outwards produces on a body when impinging on it must also be produced, in like circumstances, but in an opposite direction, by the force moving inwards.

7. If, then, there be in reality an elastic medium, and if any of the phænomena of nature are produced by motions impressed on its particles, then, so far as these phænomena are

B 2

concerned, an atom of matter must be defined as a centre from which force (understanding by the word force merely motion, or the cause which produces those results which take place when one elastic body comes into collision with another) is constantly flowing, and back to which an equal force, from points inconceivably distant, is constantly returning; or as a centre to which, from all directions, force is constantly flowing, and back from which it is again reflected.

8. Let all the force which emanates from, or impinges on, an atom at any one instant, be called a curve of force. The whole system may evidently be divided into two series of such curves, one flowing outwards from, and one flowing inwards to the centre. The term curve is used in contradistinction to that of wave or undulation; for, if these curves emanate from, and impinge on, an atom at regular intervals, the result must be a uniform, and not an undulating force in either direction.

9. Let the velocity of the particles of the medium be supposed the same at all distances from the centre, basing, for the present, the assumption on the analogy of light. But by this uniform velocity must be understood not only the uniformity at all distances of the velocity of the force flowing to and from any one atom, but also that the force flowing to and from every atom must possess the same velocity. This condition is evidently necessary to the stability of such a system as has been described. When, therefore, there is more force flowing to and from one atom than another, the distance between the successive curves must be less in the one case than in the other, and the one atom must be larger than the other.

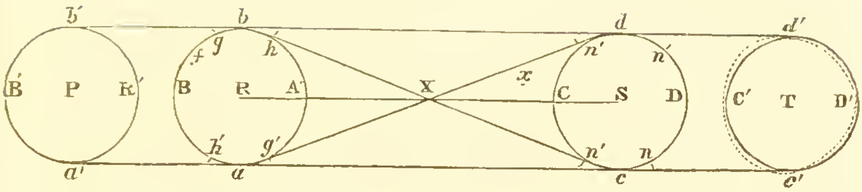
10. Let the form of an atom depend on the distribution of the pressure on its surface.

11. When a curve is said to be of its ordinary tension, it is to be understood that the particles of the medium which constitute the curve are exactly at that distance from each other at which elasticity ceases—the distance between the successive curves always exceeding this distance.

CHAPTER II.

ON GRAVITATION.

Fig. 1.



12. Let R and S be two equal atoms of matter, at such a distance from each other that, at S, the rays of force flowing to R may be considered parallel.

Leaving P and T out of consideration for the present, outer hemisphere *d* D *c* of S must intercept a part of the force flowing to inner hemisphere *b* A *a* of R; but, as this latter must intercept an equal portion of the curve flowing from S, the pressure on it must remain unaltered. Outer hemisphere of R, however, whilst its own inward curve impinges on it unaltered, must intercept a portion of the force flowing to S; and, the pressure on the outer being thus greater than the pressure on the inner hemisphere, R must move toward S. Similarly, S must move toward R. The force with which the two atoms thus approach each other must evidently increase as the square of the distance between them decreases.

13. If no force had emanated from atom R, then, after passing R, the elasticity of inward curve S would, as it contracted, have pressed the parted ends *a* and *b* together; and, when the curve reached the atom, the force would have been equally distributed over both hemispheres. If the effect of this resistance be to cause the force of inward curve S to proceed, after passing R, in straight lines toward every point of the

inner hemisphere of S, then, between the atoms, the medium must be in a state of equilibrium, and the total force impinging on the inner hemisphere of S be the ordinary force of the curve: for the forces moving from and to R and S must compensate each other at all points, that is, be exactly equal to each other at all points; and, when this is the case, the velocity of the force, and consequently the tension of the curves, must remain uniform at all points, and the system be in a state of equilibrium.

Thus, in the triangle $c X d$, at any point x, the force of inward curve S, lost by the interposition of R, must be measured by the angle $a x b$; similarly, outward curve R at the same point is measured by the angle $a x b$; hence the total force flowing to and from the inner hemisphere of S must be the ordinary force of the curve. The force of inward curve S being, at $a c$, the ordinary force of the curve, whilst at $X c$ it is the ordinary force, less a quantity equal to outward curve R, there must be, in the triangle $c X a$, a force flowing to S, equal at $a c$ to outward curve R, and decreasing to nothing at $X c$; this force thus exactly compensating inward curve R in the triangle $c X a$.

14. The portion of the outward curves intercepted by the inner hemispheres being equal to the portion of the inward curves intercepted by the outer hemispheres, these latter must exactly replace the former; and beyond the atoms the curves may be considered as flowing on undisturbed. For it is to be observed, that the particular direction in which the portions of the inward curves impinging on the outer hemispheres of the atoms move after reflection, must depend solely on what is necessary to produce or maintain equilibrium in the medium.

15. In the same manner, the state of equilibrium between the atoms might have been shown; thus, if the inward curve S be supposed to flow on undisturbed after passing R, that part of outward curve R which emanates from its inner hemisphere must be less than its ordinary force by a quantity equal to the portion of inward curve S intercepted by R. If

outward curve R, thus reduced in force, expanded equally in all directions, then below $a\,c$, and above $b\,d$, the force flowing from R would be less than the force flowing to it, whilst, between $a\,c$ and $b\,d$, the force flowing from R would be greater than the force flowing to it. But the pressure, calculated in the direction of curve R, decreases from the axis toward $a\,b$ and $c\,d$; hence the uncompensated force R must be pressed back from the axis, till the other parts of the curve are restored to their ordinary force; and this would evidently be the case, if, when reaching S, outward force R were totally expressed from between $a\,c$ and $b\,d$.

16. Suppose, then, atom S to be moved transverse to the axis, till the point d coincides with the point S, and atom T to be moved till the point c' also coincides with S. If, then, reasoning as in the preceding section, inward curves S and T be supposed to flow on undisturbed by the interposition of R, outward curve R must, when it reaches S and T, be totally expressed from the space between the lines joining $a\,c$ and $b\,d'$, and the force of outward curve R, above and below these limits, be the ordinary force of the curve, and the system be in a state of equilibrium. If, then, when T occupies the position on the axis behind S, inward curves S and T still flow on undisturbed after passing R, that portion of outward curve R which before impinged on T must now impinge on S, and the curve, as before, be in a state of equilibrium, if it be pressed back from the axis, in every direction, to a distance equal to $c\,d=2\,c\,S$; but the force which now presses outward curve R back from the axis is the combined force of inward curves S and T, and the effect on it should therefore be double that in the case of two single atoms (leaving out of consideration the difference between the distances R S and R T).

Again, the distance from the axis to which outward curve R is pressed back must reach a maximum at S; because, beyond S, the intercepted portion of inward curve S must be restored to curve R. Similarly, inward curves S and R flow-

ing on undisturbed after passing T, outward curve T must be pressed back from the axis to a greater distance than *d d′* or *c c′*, and this distance must also reach a maximum at S. At S, inward curve R must thus be of its ordinary force, and outward curve R less than its ordinary force by the intercepted portion of the inward curve T. Again, inward curve T must be of its ordinary force, and outward curve T less than its ordinary force by the intercepted portion of inward curve R; but the force of inward curve R intercepted by T must be equal to the force of inward curve T intercepted by R; hence, at S, inward curve T, plus outward curve R, must be equal to inward curve R, plus outward curve T, and the total force moving toward T be equal to the total force moving toward R. In these circumstances, inward curve R may be considered as equal to outward curve R, and outward and inward curves T as of their ordinary force. Between S and R, inward curve R must expand toward the axis, whilst flowing from S to R, precisely as, whilst flowing from R to S, outward curve R was pressed back from the axis; and the force which impinges on the inner hemisphere of R be the ordinary force of the curve; and, between R and S, the forces must compensate each other at all points. Similarly, the force which impinges on the inner hemisphere of T must be the ordinary force of its curves; and, between T and S, the outward and inward forces must exactly compensate each other.

As, then, the equilibrium of the system is maintained when the outward curves expand, as has just been described, the elasticity of the medium must produce such an expansion, and the result must be precisely the same, whether T occupies a position on the axis behind S, or a position above it.

For, in the former case, the force which impinges on the inner hemisphere of S must be the ordinary force of the curve, plus a portion of inward curve T, equal to what would have been intercepted had R not been present. Similarly, the force impinging on the outer hemisphere of S must be the

ordinary force of the atom, plus a portion of inward curve R, equal to what would have been intercepted had T not been present. Any two of the atoms must therefore act on each other precisely as if the third were not present; and this must evidently hold true, whatever be the number of the atoms. Hence, if R and S represent two masses or collections of atoms, the force with which they act on each other must be equal to the number of atoms in the one, multiplied by the number of atoms in the other, divided by the square of the distance between their centres.

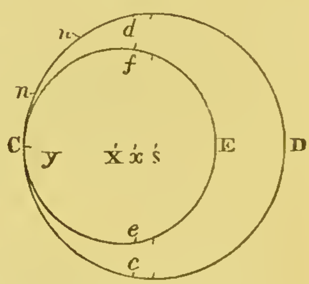
17. It may be objected to the foregoing demonstration, that it can only be true up to a certain limit. For, let S represent a mass, and R a single atom, the former may be so large that the force of its inward curves, intercepted by R, may be equal to the ordinary force of that atom; and therefore any further increase of mass S would not be attended with an increase of attraction between R and S. But if mass S be composed of an infinite number of parallel rows of atoms, each row being infinitely long, the total force flowing toward S, intercepted by R, may be calculated. Inward force S, intercepted by R, must be at a maximum when the distance between R and the nearest atom of S is equal to the distance between the constituent atoms of S. In these circumstances it will be found that, when the distance from centre to centre of the atoms is about 15 radii, the force S impinging on any point of R cannot equal the ordinary force of the atom impinging on that point.

From the reasoning in the succeeding chapter, it may be concluded that two atoms can never approach each other more closely than about 7 radii, and that, in all probability, the distance at which they come to rest must be much greater. But, practically, the atoms of a mass are never arranged as above described. Experience tells us that the constituent atoms of a mass are arranged in groups or crystals; that these, acting on each other as single atoms, form larger groups; and these again combine, forming still more complex groups. But if

a number of atoms arrange themselves so as to form a sphere, and two such spheres approach until their nearest points are at the same distance as the constituent atoms of either sphere (not a very probable supposition), then the average distance between the atoms must be nearly twice as great as the distance between any two atoms in the sphere; for the contents of a sphere is little more than half its circumscribing cube. When, then, a number of spheres combine into a larger sphere, and these again into one still more complex, the average distance between the atoms must be very greatly increased. Although, then, the primitive form of a crystal may not be a sphere, still, as it cannot be a cube, the conclusion must hold good to a very considerable extent; and, when we reflect that the smallest crystal cannot be a simple group sueh as first described, but must be formed by the combination of such to a very great degree of complexity, it is evident (without taking into account the expansive aetion of heat) that the limit deseribed at the commencement of the section can never be reached, or even approximated to at all closely.

18. S being put in motion, let the action of R eease. Let S X be the distance travelled by S between the emanation of two curves. E C, the first curve emanating from the atom after motion has commenced, must radiate from X, whilst S must still be the centre of the inward eurves. Let D C be the first inward curve E C meets. The partieles whieh before eontact constituted the outward curve, must after contact constitute the inward curve, and *vice versâ*. C must be the first point at which the two curves come in contact. Whenever any point in the hemisphere C D d comes in contact with the outward eurve, the eorresponding point in c C d must (had the velocity remained unchanged) have travelled over a space equal to one-half S X eos θ (x, midway between S and X, being the origin);

Fig. 2.



and x, after contact, must have become the centre of the curve. But f C e being greater, and c C d less, than a hemisphere, the velocity of the latter must be increased after contact: on the other hand, f E e being less, and c D d greater, than a hemisphere, the velocity of the latter must be decreased after contact. This decrease of velocity must be greatest at D, decreasing as the cosine to nothing at c and d; and the increase of velocity must be greatest at C, also decreasing as the cosine to nothing at c and d. But, in consequence of this excess of velocity, c C d must expand more rapidly than c D d; and the particles of the medium must therefore pass from the latter to the former portion of the curve, until the number of particles in c C d equals the number in f C e, when the velocity must again have decreased to its ordinary rate; for the same force now puts in motion the same number of particles that it did before contact. When this occurs, the velocity in c D d must again have increased to its ordinary rate; and X must evidently be the centre of the curve. The changes in the velocity of the different parts of the curve acting in the same direction, thus double what would have been the effect of contact on the curve had the velocity remained undisturbed.

19. Again, C must have been the first, and E the last point of C E to come in contact with C D; and, had the velocity remained unchanged, x must, after contact, have become the centre of the curve. But c C d being less, and f C e greater than a hemisphere, the velocity of the latter must be decreased after contact. On the other hand, the velocity of e E f must be, to an equal extent, increased after contact. As, after contact, C E is a contracting curve, this change in the velocity of the different parts of the curve must act as a force moving the centre in the direction S X, and must therefore neutralize what would otherwise have been the effect of contact; so that X must, after contact, remain the centre of C E.

When, therefore, an atom is in motion, the curves ema-

nating therefrom must be considered as flowing on undisturbed by the action of the inward curves; whilst these latter must have their centres always brought to coincide with that of the last outward curve with which they have come in contact. When, therefore, an inward curve impinges on an atom in motion, the centre to which it tends must be the point occupied by the centre of the atom, when the curve immediately preceding was reflected from it. The distance of this point from the centre of the atom must be very minute; but, owing to this cause, there must be a proportionately smaller part of the curve impinging on the hemisphere of the atom corresponding to *f* C *e* than on the other. But the parts *f* C *e* of the atom and curve are moving in opposite directions, whilst the parts *f* E *e* of the atom and curve are moving in the same direction; the former part of the curve must therefore impinge on the atom with greater force than the latter, thus maintaining the equality of the action on both hemispheres, and the stability of the system.

When, therefore, an atom is once put in motion, it must, so far as the forces of which it is the centre are concerned, move on in a straight line for ever.

20. When, therefore, two masses continue to act on each other, the velocity with which they approach must increase as the time of action, supposing the force of gravitation to remain constant.

21. If R move in the direction *a b*, the force flowing to and from S must impinge with increased force on the hemisphere B *b* A, and with decreased force on the hemisphere B *a* A, thus retarding the motion of R. This retarding action is not peculiar to the doctrine of a medium; it is equally the result of the theory of emission. Thus, if gravity consist of particles emitted from the sun in straight lines, these particles must evidently impinge with greater force on the hemisphere B *b* A than on the hemisphere B *a* A, of R when moving in the direction *a b*. This retarding action must evidently increase as the velocity, and decrease as the square

of the distance increases. The velocity of the earth being about the $\frac{1}{10000}$th part of light, this retardation, supposing gravity to move with the same velocity as light, must amount to nearly three-quarters of an hour in one revolution. Besides this, there is at least one other retarding action; but this, as also the force which neutralizes both, will be considered in a future chapter.

CHAPTER III.

ON POLARITY.

22. So long as the distance between R and S continues so great that the intercepted rays of force may be considered as parallel, the two atoms must retain their spherical form ; but, as the distance between them decreases, the intercepted rays become more and more convergent, and the form of the atoms must change, because

1st. The intercepted rays being no longer parallel, the same extent of surface, at different points of the outer hemisphere, must sustain different amounts of pressure.

2nd. The length of the atom's radius being now an important element in the calculation, the increase, from D to *d* and *c* in the force of the intercepted portion of inward curve R, can no longer be disregarded.

3rd. The action of inward curve R can no longer be considered as confined to the outer hemisphere of S; and therefore, as the atoms approach each other, the pressure on the inner hemispheres must increase. The quantity of outward curve R impinging on point C must then exceed the quantity of inward curve S intercepted from the same point by R ; and thus, when the distance between the centres of the atoms is about three diameters, the pressure on the point C of the inner hemisphere must equal the pressure on the point D of the outer hemisphere.

At *c* and *d*, points equally distant from R, the only force pressing upon the atom, in addition to its own curves, is that of inward curve R; hence the pressure on these two points must always be equal.

As C is the point of S nearest to R, the force of outward curve R impinging on the inner hemisphere of S must de-

crease from that point towards *c* and *d*; but the force of inward curve R, impinging on the outer hemisphere, increases from D to *c* and *d*. Therefore, although the forces pressing on C and D and *c* and *d* are respectively equal to each other, yet the pressure on the other points of the outer hemisphere must be greater than the pressure on the corresponding points of the inner hemisphere; and, if the necessary calculations are made, this excess will be found greatest at the points *n*, 60° distant from D.

23. Deducting the pressure on the inner hemisphere from that on the outer, there remains on the latter a force nothing at C, *c* and *d*, and greatest at the points *n*. These latter points must therefore be pushed further in, toward the line joining *c* and *d*, than the other points of the hemisphere; whilst the corresponding points of the inner hemisphere are pressed further out, thus producing a figure similar to that represented by the dotted line, atom T. At D′, in the outer hemisphere, the curvature must be greater than that of a circle; whilst, at the corresponding point C′ of the other hemisphere, the curvature must be to the same extent less than that of a circle. At the points *n*, the curvature must be less than that of a circle; whilst at the corresponding points *n*′, the curvature must be greater than that of a circle.

From these peculiarities in the form of the atom may be deduced the principal phænomena of polarity.

Let the hemisphere *c*′ D′ *d*′ be called positively, and the hemisphere *c*′ C′ *d*′ negatively polarized.

24. When an atom has thus been polarized, the curves thereafter emanating from it must be similarly polarized; but the inward curves, until acted on by the outward curves, must continue spherical.

In the hemisphere *c*′ C′ *d*′, the point C may be considered as a point in a circle radiating from a centre between T and D′. The corresponding point D′ of the opposite hemisphere may be considered as radiating from the same point. The points *n*′ may be considered as points of a circle radiating from a centre

between C′ and T′, and the corresponding points *n*, in the opposite hemisphere, as radiating from the same point. Every point in the one hemisphere may thus be considered as radiating from the same point as the corresponding points in the other hemisphere. But, according to sec. 19, when the centres of the outward and inward curves do not coincide, the outward curve flows on unchanged, whilst the centre of the inward curve is brought to coincide with that of the outward curve.

When, therefore, an outward polarized curve comes in contact with an inward spherical curve, the centres of the different points of the latter must, as the action on both hemispheres must be equal and coincide in direction, coincide after contact with the centres of those points of the outward curve with which they were in contact, and the inward curve be consequently polarized similarly to the outward curve.

25. When an atom is polarized, as the quantity of matter in it remains the same, its surface must be increased; for the surface of a sphere is less than that of any other solid of the same content.

When, therefore, the polarity of a curve is increased equally in both hemispheres, the diameter *c d* must be reduced.

26. If, however, a force, increasing the polarity of a curve, act only on one hemisphere of that curve, the surface of, and force in, that hemisphere must increase, whilst the surface and polarity of the other hemisphere must decrease. Thus, supposing the force were pressed from *c*′ C′ *d*′ to *c*′ D′ *d*′, the outward pressure would act to the greatest advantage at D′, that being a point of greater curvature. Or if the force were pressed from *c*′ D′ *d*′ to *c*′ C′ *d*′, the pressure would act with greatest effect at the points *n*′; the effect in either case being to increase the polarity of the hemisphere according to the increase of the force. In the same manner, had the force been drawn from either hemisphere, the action would have been greatest at the points of greatest curvature, thus producing a decrease in the polarity of that hemisphere.

27. When an outward curve, thus unequally polarized in

the two hemispheres, acts on an inward curve, either spherical or equally polarized in both hemisphores, then the corresponding points in the two hemispheres cannot radiate from the same centre, as in the former case ; the point C, for example, supposing c' C′ d' to be the more strongly polarized hemisphere, radiating from a point farther from T than the point D′, it follows, that the effects of contact on both hemispheres of the curves cannot coincide in amount, and that the result must consequently be a mean between the two actions ; that is, the difference between the polarities of the two hemispheres of the outward curve must be reduced one-half, and a difference to this extent be produced between the two hemispheres of the inward curve.

28. When an inward polarized curve impinges on a spherical atom, the parts of less curvature must impinge on the surface of the sphere before the parts of greater curvature, and those parts of the atom thus be pressed inward, and the others outward, for a time, thus bringing the surface of the atom and of the curve into coincidence, and polarizing the atom similarly to the curve. The polarity of the atom, supposing no other force to act on it, must depend on the polarity of the inward curves ; but as, supposing the polarizing force to cease, the polarity of an inward curve can never exceed that of the last outward curve with which it was in contact ; and, as the polarity of an outward curve must always somewhat decrease during the time which elapses between its emanation from the atom and its coming into contact with an inward curve, it results that each successive inward curve must impinge on the atom with a weaker polarity than its predecessor, and the polarity of the atom very speedily become so reduced that it may, practically speaking, be called depolarized.

29. When a portion of an inward polarized curve is intercepted by, and reflected back from, the outer hemisphere of an atom, its polarity must be unchanged ; because from those parts of the atom on which a greater quantity of force impinged, must a greater quantity be reflected ; and, when

equilibrium is restored, the curvatures of those parts must be, to the same extent that they were before contact, greater than those of the other portions of the curve.

30. Hitherto the action of an outward upon an inward curve has alone been taken into consideration; but two outward curves may act on each other. In the former case, a convex surface acted on a concave, the result being to assimilate the polarity of the former to the latter; in the present instance, two convex surfaces act on each other with precisely opposite results.

The consideration of this case will be simplified by calling that part of outward curve R which emanates from the inner hemisphere pole A, and that from the outer hemisphere pole B; similarly calling that part of outward curve S which emanates from the inner hemisphere pole C, and that from the outer hemisphere pole D.

31. In the first case, let R be a polarized, and S a spherical atom; and let R, for facility of explanation, have its inner hemisphere positively polarized.

Between the lines *a c* and *b d* (fig. 1), outward curves R and S must act on each other; but, at all other points, outward curve R must be meeting the equal and similarly polarized inward curve R, and outward curve S the equal inward curve S; so that the mutual action of curves R and S must be confined to the space between *a c* and *b d*.

32. Between S and X, outward curve S must meet curves partially composed of inward curve S and outward curve R; hence outward curve S may be considered as divided into two portions, one equal to inward curve S, and one equal to outward curve R, when spherical. Similarly, between R and X, outward curve R may be divided into two portions.

The action of an outward upon an inward curve having been already investigated, it will only be the action of the latter portion of curve S on outward curve R which will now be taken into consideration.

33. Let the action commence close to R. Outward curve

R being polarized, and curve S spherical, the surface of the former must be greater than the surface of the latter, and as, during contact, the two surfaces must be brought to coincide, it follows that pole C must have its surface somewhat increased, and pole A its surface to an equal extent decreased. Pole A being positively polarized, the point A must be a point of curvature greater than that of a circle; hence, after contact, the velocity of point C of outward curve S must be somewhat diminished, the force having to move a greater number of particles than before. On the other hand, the points n' of curve R being of curvature less than that of a circle, the corresponding points in curve S must have their velocity for a time increased after contact. The action so far coincides with that of an outward and inward curve; but, the curves being now expanding curves, an increase of velocity at any point must be attended with an increase of curvature, and a decrease of velocity with a decrease of curvature; hence pole C of curve S must be negatively polarized by the action of R. Curve R, after contact, must flow on with polarity unchanged in kind, but reduced in amount; for it is only pole A on which there is any disturbing action, the other poles of the outward and inward curves coinciding: hence the result must be according to Sect. 27.

34. It is to be observed that the polarity induced on curve S is confined to the space between $a\,c$ and $b\,d$; that is, the portions of the curve whose curvature is alternately increased and decreased lies wholly between these lines. But when atom S is polarized, the action of pole C on pole A must have a similar tendency; hence, when two polarized atoms act on each other, the tendency of their action is to confine each other's polarity to the space between them, and, for at least some distance, to the similar space beyond them.

35. When poles A and C are oppositely and equally polarized, their mutual action can produce no disturbance of the equilibrium. Supposing, then, the polarity of pole A constant, this disturbing action must increase as the polarity of pole C

decreases, being at a maximum when the polarity of pole C is at a minimum. Supposing the polarity of pole C (reversed in kind) again to increase, the disturbing action would again decrease; and when the two poles were equally polarized, the action would coincide with that of an inward and outward curve in the same circumstances. But the increase of polarity induced by pole A upon C, whilst its positive polarity increased from zero to a maximum, must be opposite to that of pole A (that is, negative); but the polarity of pole C being positive, this induction of negative polarity upon it must be equivalent to a reduction of its positive polarity. When, therefore, two similar, but unequal, poles act on each other, the tendency of their mutual action is to depolarize each other.

36. When outward pole A impinges on atom S, the two surfaces being convex, the polarity induced by pole A must be negative. Inward pole A being concave, the polarity induced by it on the outer hemisphere of S must be positive, and the action of outward and inward poles A upon S thus coincide.

37. It has been shown (Section 32) that outward curve S may, between S and X, be divided into two portions; the former equal to inward curve S, and the latter portion equal to outward curve R. But this is only strictly true when the atoms are spherical; for, as the distance of a polarized curve from its centre increases, its polarity, as well as its force, decreases. When, therefore, R and S are equally polarized, the surface of the latter portion of curve S must, between S and X, be greater than that of curve R, and pole A, as it approaches S, must be constantly meeting curves more strongly polarized than itself. This must be the case except at very short distances, whether the atoms are equally polarized or not; for whenever pole A, when it has approached very closely to S, is stronger than pole C, the polarity of atom S must be so weak that, practically, its form must be spherical.

38. As the surface of a curve is greater when polarized than when spherical, it follows that, should the polarity of pole A,

whilst flowing from R to S, be increased or decreased, the portion of outward curve R intercepted by inner hemisphere S would be greater or less than the portion of inward curve S intercepted by outer hemisphere R.

39. We are now in a position to trace the action of two polarized atoms on each other.

Let R and S be two oppositely polarized atoms. As pole A approaches S, it must, between S and X, be constantly meeting poles, C, more strongly polarized than itself; and therefore, as pole A approaches S, its polarity must be increased by the action of poles C. This increase of pole A must act as an increased resistance to the expansion toward the axis of inward curve S, and an increased portion of that curve must be pressed from the inner to the outer hemisphere of S, thus increasing inward pole D, and decreasing inward pole C.

The increase of outward pole A must thus be neutralized by the decrease of inward pole C, and the force flowing to inner hemisphere S be neither increased nor decreased.

Again, the increase of outward pole A must be attended with a decrease in outward pole B. This must produce a decrease in inward pole B, and an increase in inward pole A; but the increase in outward pole A is accompanied by an equal decrease in outward pole C. The increase in inward pole A, and decrease in outward pole C, must therefore neutralize each other, and the total force flowing to and from inner hemisphere S have suffered neither increase nor decrease. The decrease in outward pole C must produce an equal increase in outward pole D. Inward and outward poles D being thus both increased, the force impinging on the outer hemisphere of atom S must be increased accordingly.

As yet inward pole A impinges on the outer hemisphere of S with unaltered force, and S consequently intercepts a greater portion of outward than of inward curve R; but to exactly the same extent the force with which inward pole D impinges on the outward hemisphere exceeds the force with which inward pole C impinges on the inner hemisphere of S. The total force

reflected from the outer hemisphere of S is therefore equal to outward curve S, supposing it to radiate from S equally in all directions, and to outward pole A, supposing outward curve R to flow on unchanged by the interposition of S.

But, the polarity of outward pole A being greater than that of outward pole B, a similar inequality must be produced in inward poles A and B; and thus, ultimately, inward pole A must impinge on outer hemisphere S with the same force that outward pole A impinges on the inner hemisphere.

When this takes place, the increased force with which outward pole A impinges on the inner hemisphere of S being neutralized by the decreased force of inward pole C, the total force impinging on the inner hemisphere remains unaltered; whilst inward poles D and A both impinge on the outer hemisphere with increased force, and the attraction between R and S must be increased accordingly.

40. The action of outward pole C being to increase outward pole A, and decrease pole B, whilst, as inward curve R is equally polarized in both hemispheres, its action must tend to reduce the inequality produced in the poles of outward curve R, the actions of outward pole C and inward pole A on outward curve R must thus be opposed to each other, and, when equal, no further increase in the polarity of pole A can take place.

41. When R and S are similarly polarized, the action must be exactly the reverse of two oppositely polarized atoms. For outward pole A must be decreased as it approaches S; hence inward pole C must increase, and inward pole D decrease, the total force flowing to inner hemisphere S remaining unchanged. But the decrease in outward pole A must produce a decrease in inward pole A, and the force of outward curve S must flow from the outer to the inner hemisphere of the curve, and thus restore the equality between the force flowing to, and the force flowing from, each point of S; hence the force impinging on the inner hemisphere of S must be the ordinary force, whilst the force impinging on the outer hemisphere must be to a certain extent decreased. But to this extent inward pole A,

remaining as yet unaltered, must impinge on the other hemisphere with a force greater than that with which outward pole A impinges on the inner hemisphere. The total force reflected from the outer hemisphere is therefore equal to the ordinary force of curve S, outward curve R being supposed to flow on unchanged after passing S. But the action of outward pole A must, in these circumstances, ultimately reduce the force of inward pole A, impinging on the outer hemisphere of S, to an equality with the force of outward pole A impinging on the inner hemisphere. When this takes place, the force with which the two atoms approach must be reduced to an extent equal to twice the decrease in the force with which outward pole A impinges on inner hemisphere S. When the force with which pole A impinges on inner hemisphere S is reduced more than one-half, a repulsive action must result. But, in ordinary circumstances, two similarly polarized bodies, if at rest before polarization, must always repel each other after polarization, for the attraction must then be less along the line R S than in any other direction.

42. If S and T, and P and R, be oppositely polarized to each other, then, as when R is oppositely polarized to S, it must also be oppositely polarized to T, and P must also be oppositely polarized to S and T, the polar action of masses must obey the same law as gravitation.

But, as when such an arrangement of the poles of the constituent atoms of a mass is produced, the arrangement is nearly superficial, the polar action practically depends on the extent of polarized surface, without reference to the mass.

43. When S and T are similarly polarized, then the force of inward and outward pole C must be less than its ordinary amount, so long as the action of S upon T is unopposed; hence outward pole A must, as it approaches S, be constantly meeting poles C weaker than itself, and outward pole A must therefore decrease; this must produce a decrease in inward pole A, and there must thus arise a tendency in outward and inward curves S to flow from hemisphere D to hemisphere C.

The action of R, whether it be similarly or oppositely polarized to S, is thus destructive of the repulsion between S and T, and is therefore equivalent to a repulsive action between R and S. If, then, P and R be similarly polarized, the polar action of the two masses P R and S T must always be repulsive.

This conclusion is one involving results of great moment; it may, however, I think, be arrived at without reference to any theory or hypothesis regarding polarity, but merely by reasoning on observed facts.

When two oppositely polarized bodies attract each other, they increase each other's polarity, and the attraction between them must consequently depend, not directly on the strength of the opposite polarities at the commencement of the action, but on the amount of polarity generated by their mutual action; for, were it not so, the attraction between them would increase more rapidly than the square of the distance decreased. Thus, let R and S be oppositely electrified, the attraction between them increases as the square of the distance decreases; but the quantity of electricity upon either body also increases as the square of the distance decreases; hence it is evident that the increased attraction between R and S depends wholly on this increase of electricity; for, were it not so, the attraction would be inversely as the fourth power of the distance. If, then, from any counteracting cause, no increase of electricity resulted from the mutual action of R and S, no electrical attraction would take place between them. On the other hand, when similarly polarized, their mutual action tends to destroy each other's polarity; but the resulting repulsion cannot be measured by this decrease of polarity, for it would in that case be greatest when the two bodies completely depolarized each other; but, as is well known, the continuance of the repulsion is measured by the strength, and depends on the maintenance of the similar polarity in the two bodies.

Hence, then, if R and S be oppositely polarized, and all increase of their polarities by their mutual action is prevented by the action of T upon S, and P upon R, R and T must act

on each other precisely as if S were not present. This conclusion is not exactly the same as that deduced from theory; R, in the one case, having no polar attraction whatever upon S, whilst, in the other, it may repel it. But at the same time it is, at least, not an improbable conclusion that, when the action of T upon S is greater than the action of R, the action of the latter may not only be counteracted, but reversed.

44. Resuming the consideration of the action upon each other of two spherical atoms at short distances; it has been shown (section 22) that the outward force impinging on the inner hemispheres increases more rapidly than the inward force impinging on the outer hemispheres; and that this excess of force is greatest at point C, decreasing toward points *c* and *d* of atom S. The total force of outward curve R impinging on S must equal the total force of inward curve R impinging on S; but part of this latter curve impinges on the inner hemisphere of S: when, therefore, outward curve R passes S, it must require, to restore it to its ordinary force, not only the force of inward curve R, intercepted by the outer hemisphere, but also the part of that curve which impinged on the inner hemisphere; this latter therefore must be forced from the inner to the outer hemisphere. Hence the inner hemisphere of outward curve S must be positively polarized, there being an increase of force at C and a decrease at the points n'. Similarly, inner hemisphere of outward curve R must be positively polarized; this similar polarity of the two curves must give rise to a repulsive action between the atoms, and when the attractive and repulsive actions counteract each other the atoms must come to rest.

45. As shown in Section 23, the convergency of the rays of inward curve R tend to produce positive polarity in the outer, and negative polarity in the inner hemisphere of S. This, and the action described in the preceding section, must therefore oppose each other, and, should the two actions be equal, which is highly probable, as they both proceed from the same cause, the atoms would not in reality be polarized at all; the

polarity existing only in that portion of the curves between the atoms.

46. In the position described in the last clause of Section 22 (leaving out of consideration that pressure on the outer hemisphere, whose effect is polarity), the pressure on the atom must be greatest at C and D, decreasing to *c* and *d*; this pressure must therefore give a spheroidal form to the atoms; but whatever effects are produced by this peculiar form of the curves must be limited to a distance from the atoms very short indeed; as it is evident that two spheroidal curves could not not act on each other in the manner described in Section 34.

47. Let R be negatively polarized, and S spherical. The point A of curve R being now a point of less curvature, whilst the points *n* are points of greater curvature, the force impinging on, and reflected back from, point C cannot now be so much in excess of the ordinary force of curve S as when R was spherical, whilst the points *n'* of outer curve S cannot now be so much less than the ordinary force of the curve. But the action upon the outer hemisphere of the convergent rays of inward curve R is to produce negative polarity in the inner hemisphere of S. If, then, when R was spherical, this action was exactly counterbalanced, it must preponderate now that R is negatively polarized; and the inner hemisphere of atom S must be to this extent negatively polarized, that is, similarly polarized to R.

Let R be positively polarized; then, as A is a point of greater curvature, the force impinging on point C must exceed the force impinging on the other points of the hemisphere, to a still greater degree than when R was spherical; and the action, producing positive polarity in the inner hemisphere of S, be thus greater than the opposing action of inward curve R; and S must consequently be positively polarized. Hence, when a polarized acts on a spherical atom at a short distance, it excites in it a polarity similar to its own; the result being the reverse of what takes place at a great distance.

48. When two atoms, whose polarities are opposite, but equal in strength, act on each other at a short distance, they must evidently, if they approach sufficiently close, depolarize each other; and the ultimate results must therefore coincide with that of two spherical atoms.

49. If, however, the polarity of one of the atoms is stronger than that of the other, the weaker pole must be wholly depolarized, whilst the stronger is only partially so; and the result must coincide with the action of a polarized on a spherical atom, the atoms, when they separate, being similarly polarized, the polarity being that of the stronger pole.

50. If two similarly polarized atoms are forced close together, they must separate with polarity unchanged.

51. If two unequal spherical atoms act on each other at a short distance, they must become oppositely polarized. For, let R be twice the size of S, then its effect on S must be that of an atom equal to S, at one-half the distance; but the rays of inward curve R, impinging on outer hemisphere S, must be more nearly parallel than if flowing to a centre at half the distance; hence the effect of inward curve R, in producing negative polarity in the inner hemisphere of S, must be less than in the case of equal atoms. But the force of outward curve R, impinging on C, must exceed the force of inward curve S, intercepted from that point by R to a greater extent than in the case of equal atoms, and S must therefore be positively polarized. By analogous reasoning R may be shown to be negatively polarized.

52. In the space between two oppositely polarized atoms, when the distance is very small, the curves flowing to and from each atom may be divided into two portions oppositely polarized to each other, and the two atoms must act on each other as if they were masses whose constituent atoms are similarly polarized to each other; hence, if they approach without any accumulated velocity, they may come to rest before they are completely depolarized. But this position must be one of unstable equilibrium, because, when any force causes

them to approach each other more closely, their polarity must diminish, and, as they do not possess in their mutual action the means of restoring their polarity, they must, when so acted on repeatedly, ultimately depolarize each other.

53. When, however, two unequal atoms come to rest oppositely polarized, the position is one of stable equilibrium; because, although when forced together their polarity must be weakened, whenever they again separate, their mutual action must restore their polarities to their former strength.

54. Further, two unequal atoms must, in consequence of this opposite polarity, attract each other at short distances more strongly than two equal atoms.

55. This last conclusion accords with chemical attraction; but were the elemental atoms of chemistry simple centres of force such as have been described, the action of two such atoms would be measured by the difference of their gravitating powers, which does not accord with the observed facts of chemical action. If, however, we consider the elemental atoms of chemistry not to be simple centres of force, but groups of such centres, all connexion between their gravitating and chemical actions would cease; for it is evident that the polar action, at short distances, of such a mass would depend entirely upon the size of its constituent atoms, without reference to their number, whilst the gravitating action would be measured by the product of their number and size. Again, if such groups were composed of atoms of different sizes, their action would depend very much on the manner in which they were arranged round their common centre; thus, if S and T be two unequal atoms, and P and R also two unequal atoms, then, if R is equal to T, and P equal to S, their mutual action must increase each other's polarity; but if R had been equal to S, and P equal to T, their mutual polar action would have been reversed. Thus the same atoms, when differently arranged round a common centre, must possess different chemical characters. Again, if such a group were acted on by another composed of larger atoms, its inner hemisphere would be posi-

tively polarized; but, if acted on by one of smaller constituent atoms, its inner hemisphere would be negatively polarized. The polarity of such a group, therefore, would not be an unalterable quality, but one which is evolved by circumstances, and whose character varies with these circumstances; and this accords with the chemical action of atoms.

56. But to suppose that the elemental atoms of chemistry are not simple centres of force, but groups of such centres, is merely to suppose that the inorganic radicals are constituted similarly to the organic radicals; an idea by no means improbable, nor unsupported by high chemical authority. Further, this idea will be found to afford a simple explanation of some of the more recondite phænomena of nature.

57. Such groups might combine with others, grouping themselves round a common centre, and acting, in a great number of circumstances, precisely as simple atoms. There are thus three descriptions of atoms, which may be distinguished as follows:—a simple centre of force may be called a primary atom; a group composed of such centres an elemental atom; a group composed of such groups a compound atom.

CHAPTER IV.

ON LIGHT AND HEAT.

58. Let · · · · D·C·B·A· ·A·B·C·D · · · · represent two rows of atoms of different magnitudes. When the distance between the rows is sufficiently small, the attraction between the atoms A must exceed the attraction between the atoms A and B (Section 54); the two atoms A must therefore leave their respective masses and approach each other, becoming oppositely polarized. The effect of this must be to increase the attraction between atoms A and B; the latter atoms must therefore follow the former, but with a less velocity; and this action must extend to some distance from A, with a constantly decreasing effect. When, however, atoms A approach each other very closely, their polarity must decrease, and, if the distance between them is sufficiently diminished, they must become similarly polarized. The attraction between atoms A and B must consequently again diminish, probably altogether cease, and atoms B. C., &c. again return to their respective masses. But, as they must return with a velocity constantly accelerated, they must pass beyond their former points of rest, until the similar polarity thus induced causes them again to recede, and they must thus, for a time, oscillate to and fro with continually decreasing vibrations. If, before they come to rest, the combined atoms A are removed, and the distance between the rows continues sufficiently small, the atoms B must act on each other precisely as the atoms A did. The effect of this must be to increase the vibratory action of the atoms already in motion, and to put in motion a greater number. The action may thus be supposed to continue, and all the atoms in both masses thus be put in motion, the rapidity of the vibrations evidently depending on the rapidity with which the atoms combine.

Chemical action must thus produce vibrations in the constituent atoms of the combining masses. Similarly, it may be shown that percussion and friction must be attended with similar results.

59. It has been shown (Section 19) that, when an atom is in motion, the centre of the inward curves participates in that motion; hence those parts of the inward curves toward which the atom is moving must have their velocity decreased, and those parts of the curves from which the atom is moving must have their velocity increased.

If, then, an atom move from S to X (fig. 2), the inward curves must impinge on the atom at X at precisely the same instant that they would have done had the atom remained at rest at S. The distance, therefore, between the last outward curve reflected from the atom at S, and the first curve reflected from it at X, must, in the direction S X, be diminished by a space equal to S X; because, at any point of their outward course, the curve reflected from the atom at S must have travelled over a distance equal to S X more than the curve reflected at X, whilst the time which elapses between the reflexion of the two curves remains unaltered. When, therefore, S moves toward R, the distance between the successive outward curves S must be decreased in the direction S R, and so far S must act on R as an atom of increased magnitude, and an increased portion of inward curve R be pressed from the inner to the outer hemisphere of that atom.

On the other hand, those parts of the inward curves flowing to the inner hemisphere of S, having their velocity decreased by the motion of the atom, must each be somewhat later of impinging on the outer hemisphere of R than would have been the case had S remained at rest, and their action on R must therefore be that of an atom of less magnitude than S. The increased action of the outward curves must therefore be counteracted by the decreased action of the inward curves, and the attraction between R and S remain unaltered (supposing the distance S X too short to affect the force of their

mutual gravitation). If S had moved from R the same result would have been obtained, the decreased action of the outward curves being counteracted by an increased action of the inward curves. When, therefore, an atom vibrates, another atom situated on the line of its vibration must remain unaffected thereby.

60. When S moves from S to X, the curve emanating from X meets a series of inward curves, whose centre is S. The particles which, before contact, constituted the inward curves moving towards S, must, after contact, constitute the outward curves, radiating from X: whilst the centre is thus changing from S to X, there must, as is evident from the reasoning in Section 18, be, in addition to the expanding motion, a movement of all the particles of the curve in a direction parallel to S X; and, as this action must be constantly repeated whilst the curve flows outwards, the result must be, that the motion of each point of an outward curve emanating from an atom in motion may be resolved into two,—one the expanding motion, and one in a line parallel to the direction of the atom's motion. If, then, S move in the direction *c d*, those portions of the outward curves corresponding to the point C of the atom must have impressed on them one movement in the direction S C, and one transverse thereto.

61. Again, referring to fig. 2, C is the first point at which an outward and an inward curve come in contact; the point C must therefore, for a time, be moving inward, whilst the rest of the curve is moving outward: thus C may be supposed to have returned to the point *y*, whilst *n* is just coming into contact with the inward curve; the centre to which the arc C *n* for a time tends must thus be moved from S in the direction S D. It is not, of course, meant that the disturbance of equilibrium extends at any one instant through such a large arc as C *n*, but merely that each point of the curve is so acted on successively. This, so far as the action about to be described is affected, is equivalent to a motion in the direction X S, or parallel to, but in the reverse direction of, the atom's motion,

in addition to the contracting motion in the direction of the radius.

62. When S is at rest (the distance between R and S being supposed very great), outward curves S act only in the hemisphere *a* A *b* of R, the points *a* and *b* being the limits of the action; when, however, S is in motion, then *a* A *b* cannot be the hemisphere on which outward curves S act; for these curves, participating in the motion of S, must evidently act in the quadrant *a* B to a distance from *a*, depending on the velocity of S, and must cease to act in the quadrant A *b*, when at an equal distance from *b*. On the other hand, the inward curves must, in consequence of the action above described, act in the quadrant A *b* to some distance from *b*, and cease to act at an equal distance from *a* in the quadrant *a* B.

Suppose, then, that S, moving in the direction *c d*, *h* A *h'* becomes the hemisphere on which outward curves S act, and *h* B *h'* that on which inward curves S act, the direction of R's motion must evidently be a line perpendicular to *h h'*.

The motion of R produced by S may therefore be divided into two,—one toward the centre of S, and one transverse thereto, but in the reverse direction to that in which S is moving. If, then, S vibrates between the two points *c* and *d*, the distance R S may be taken so very great that the distance *c d* is, in comparison, a mere point, and the attraction of R toward the centre of S may be considered as exerted always in one line. If, then, the attraction of S upon R was counteracted before S commenced to vibrate, it must continue to be so afterwards; but the transverse motion of R would still remain, for the transverse motion of the particles of the curves, depending on the distance between the centres of the outward and inward curves, must evidently remain unaffected by distance: hence, in these circumstances, the vibration of S would induce a vibratory motion of R in a parallel direction; the motion of the one atom, however, being always the reverse of that of the other. Hence it follows, that whenever a ray of light, supposing light to be caused by a vibration of the atoms

of matter, acts upon a body, the vibrations excited in that body must always be transverse to the direction of the ray; for, supposing S a mass or collection of atoms, all vibrating in the direction of tangents to its surface, the rays whose directions are transverse to the tangents would always form the front of the wave.

63. After passing R, outward curves S must flow on unchanged by the interposition of R; hence beyond R the transverse motion of the particles of the curves must continue; and, therefore, when the curves impinge on P, they must act on it precisely as they did on R. But outward and inward curves S excite vibrations in R, and the motion of R is always contrary to that of S. When, therefore, curves R act on P, they must excite a vibratory motion in P; but the direction of P's motion induced by R must be in the reverse direction to that induced by S: hence, if the effect of the vibration of R is equal to that of S, no motion will be excited in P. The transverse motions of the curves R and S, being in opposite directions, interfere and destroy each other's effects.

But, according to the undulatory theory of light, the undulations emanating from a body interfere and destroy each other at all points, except those forming the front of a wave. Considering R as a mass, and not as a single atom, if the rays in a beam of light incident upon R be all parallel to R S, the vibrations excited by curves S must be all in a direction transverse to R S; consequently the front of the wave must be a line transverse to R S, and equal to $a\,b$; it is only, therefore, in the space between the lines $a\,a'$ and $b\,b'$, that the undulations emanating from R and S can interfere and destroy each other's effects; hence these lines must form the boundary between light and darkness, the result being the same as if the rays of light moved in straight lines from S, and the further progress of those between $a\,a'$ and $b\,b'$ was prevented by R.

64. From the foregoing reasoning it would appear that the cause of transparency consists in such an arrangement of the constituent atoms of a body as enables them to resist the

vibratory action of the curves emanating from a luminous body. It is only, however, when the incident rays are perpendicular to the surface that this can be the case; whenever the rays impinge obliquely upon the surface, they suffer refraction. Now it is impossible, if our previous reasoning be at all correct, that refraction can be caused by a change in the direction of the motion of the curves emanating from the luminous body; hence it necessarily follows, that in these circumstances the light must produce vibrations in the atoms of the transparent body in two directions; one transverse to the incident ray, and one whose inclination is greater or less than a right angle. The first must interfere with and destroy the vibrations of the incident ray; the second constitute the refracted ray. If this latter pass through the body without impressing vibrations on the interior atoms, it must evidently, when it reaches the opposite surface, act upon it precisely as the incident ray acted upon the other surface, provided the two surfaces are parallel; but in this case it must be the refracted ray which is interfered with, the ray not interfered with being that whose course is parallel to that of the incident ray; and this agrees with the observed facts of refraction. It is not, however, absolutely necessary to suppose that the refracted ray passes through the transparent body without acting on the interior atoms. The mass may be divided into parallel strata of atoms, or rather of crystals, and the light, on entering and quitting these crystals, act, as according to the above it probably would do, if the different strata of atoms were separate and independent bodies. This view of the case would harmonize well with the fact that refraction, *cæteris paribus*, increases with the density; for the course of the ray, in passing through the body, would be the resultant of two forces acting alternately, one parallel to the incident ray, and one more or less inclined thereto; and the direction of this resultant would depend on the breadth of the crystal, and the distance between the successive strata; the greater the latter, the less would be the refraction, and the less

the density. It is also, *primâ facie*, the more probable view of the matter; but whether it could be brought to accord with the facts of polarization by refraction is perhaps doubtful.

65. When the force producing vibrations acts perpendicularly on the surface of a body, it must act to the greatest advantage; for the only resistance to the vibratory motion of an atom must, in this case, be the action of the atom from which it is moving; whilst, if it acted in the direction of the surface, it would be resisted both by the atom from, and the atom to, which it is moving,—and this latter action must be very powerful. Hence the action of a ray of light perpendicularly incident on the surface of a body must be at a minimum; for the vibrations are transverse to the ray. Further, although the vibrations, so excited, would interfere with those of the incident ray, there would be no change of course. The greater the angle of incidence, the more nearly perpendicular to the surface must be the vibratory action of the ray, and the greater the amount of vibration produced on the atoms of the surface, and consequently the greater the change produced in the direction of the ray.

The reason why the ray should excite vibrations in two different directions is what I am unable to explain; possibly the explanation may be found in the constituent atoms of all bodies not being simple centres of force, but groups of such centres. The application of the foregoing reasoning to the action of polarized light is too obvious to require entering into details.

66. When a ray of light falls upon a surface, the vibrations excited in the atoms of that surface cannot give rise to a transverse motion of their curves as powerful as that of the incident ray; hence light must act on all bodies to some little depth from the surface.

Supposing R and P thus put in vibration, if the transverse motion of outward curves R and P coincide in direction, the quantity of light reflected from the surface must be equal to the sum of these transverse motions; but the action of out-

ward curves P on atom R must, in these circumstances, tend to produce a motion of that atom in the opposite direction to that caused by the incident ray. Similarly, the action of curves R on atom P must be opposed to the action of the incident ray; hence the quantity of light reflected from a surface can never exceed, if it ever equal, the quantity incident. Further, when the incident ray ceases to act, the motions of R and P must immediately cease, for their mutual action is destructive of each other's motions.

67. On the other hand, had the transverse motions of outward curves P not coincided with those of R, they would have interfered, and either partially or wholly destroyed each other's action. In the latter case, no light would have been reflected from the surface, the whole being apparently absorbed. But the action on atom R of curves P is now to produce a motion of that atom, coinciding with that produced by the incident ray; and thus the mutual action of R and P, in these circumstances, increases their vibratory motion. Hence, supposing the action of the incident ray to cease, the vibration of the atoms would not cease, but, acting on the other atoms, the body must become a centre radiating heat, the amount of which must be at a maximum when the interference of the transverse motions, excited by the incident ray in the curves of the different atoms, is total; that is, when the body neither reflects nor transmits light, but is absolutely black. It is evident that the above is merely an application of Newton's theory of the natural colours of bodies to transverse vibrations, when produced as described in Section 63.

68. When S moves from *c* to *d*, its outward curves impinge to some extent in quadrant *a* B, and to an equal extent in quadrant *b* B when moving from *d* to *c*. In the first case, those atoms on which the outward curves impinge in quadrant *a* B (considering R as a spherical mass, and not as a single atom) must have a motion impressed on them in the direction *d c*; when S moves from *d* to *c*, the outward curves no longer act in the quadrant *a* B, and the atoms which were acted upon

must return to their former position; that is, must move in the direction *c d*. But outward curves S are then acting to an equal extent in the quadrant *b* B, impressing a motion on those atoms on which they impinge also in the direction *c d*. Hence the vibrations in *a* B and *b* B must coincide, and the light emanating from S must illuminate rather more than a hemisphere; the result being identical with what would be produced were the rays of light emanating from S (supposing them to move in straight lines) slightly bent round the points *a* and *b*.

69. Hitherto the vibratory motion induced on the atoms of a mass has been considered as caused altogether by the *motions* of the atoms of the body radiating light or heat, and the resulting vibrations as being therefore always in a direction transverse to the ray. But when atom B (Section 58) commences its return to its mass, it must be oppositely polarized thereto, and when repelled from its mass, it must be similarly polarized thereto; the curves emanating from an atom vibrating from and to its mass must therefore be alternately positively and negatively polarized, according as the atom is moving from or to the mass. When these polarized curves impinge on a substance, they must, supposing no counteracting force to operate, alternately attract and repel the atoms of the substance, thus producing a vibratory action in the direction of the ray.

Hence, when a body radiates heat or light, there arise two vibratory actions, one transverse to, and one in the direction of the ray. These actions are altogether dissimilar in their nature, the latter being entirely dependent on polarity, and the former on the motion of the atoms.

70. It seems scarcely possible that the former action can exist without the latter, for a change of polarity must always be accompanied by a change in the relations between the adjacent atoms, increasing or decreasing their attraction, and thus producing a proportionate amount of motion.

But when atom A vibrates transversely to the line A B C, the distance between A and B must increase, but never de-

crease; hence, although the polarity may increase or decrease, it cannot, in consequence of this vibratory action, change from positive to negative, or the reverse. Further, the length of vibration remaining the same, the increase of distance between A and B can only be, in the case of transverse vibrations, one-half what it would be in the case of direct vibrations to and from B; hence the variation in the strength of the polarity can, in the former case, be only one-fourth what it would be in the latter; and, there being no alternation of polarity, the polar vibrations cannot, except in extreme cases, produce any sensible direct vibrations.

71. The vibrations arising from polarity must evidently facilitate chemical combination; for, in the two rows of atoms D·C·B·A·, ·A·B·C·D, the distance between the two atoms A may be such that their attraction for each other may not be so great as their attraction for atoms B, in which case no chemical action would take place, supposing the atoms at rest: if, however, they vibrate directly, they may approach so closely that the consequent polar attraction may overcome their attraction for their respective masses, and chemical action result; but if the atoms had vibrated transversely, no increase of attraction would have taken place, the distance A A remaining constant.

If A B C, instead of a single row of atoms, were a mass composed of a number of parallel rows, it is evident that a transverse vibration would tend to disturb the arrangement of the atoms, breaking up the existing groups into which they are congregated, and forming new ones; thus changing the chemical constitution of the substance. So far, then, the action of the direct vibrations produced by polarity agrees better with the chemical action of heat than with that of light; whilst the action of the transverse vibrations agrees better with the chemical action of light than with that of heat.

72. Supposing these direct vibrations produced by an alternating polarity to be essential to the existence of heat, whilst light depends entirely on the transverse vibrations, we can

comprehend how the light and heat of a ray may become separated in passing through certain substances. Thus, if the atoms of a substance are in a state of vibration, and alternately, similarly, and oppositely polarized, the positive polarity of the ray may coincide with the negative polarity of the curves emanating from the substance, and the negative polarity of the former with the positive polarity of the latter; and the direct vibratory action be thus neutralized in passing through even a small depth of the substance, whilst the transverse action remains unaltered.

But even a transverse vibratory action would, if very strong, be inconsistent with athermanous action, because an increase of vibration must be attended with an increase of attraction, and this would deflect the atom from its transverse course and impart to it a motion perpendicular to the surface, and thus ultimately produce an alternating polarity. This coincides with the fact that the same substance which prevents the transmission of the heat of a fire, whilst it allows the light to pass, does not, at least to nearly the same extent, intercept the heat of the sun; and it is evident that the transverse vibrations of the sun's light must be very much stronger than those of a fire.

73. When an undulating force acts on a mass composed of equal primary atoms, the vibrations induced on these atoms must be the same, whatever be their size. Thus, let the same undulating force act on two masses, the diameters of the atoms of the one mass being double the length of those of the other, the amount of force acting on each atom must be four times greater in the former than in the latter case; but the mutual action of the atoms must also be four times greater, and, so far therefore, calculated in diameters, the length of the vibrations should be the same in both cases; that is, their actual length in the former should be double that in the latter case. But, the content of a sphere being proportioned to the cube of the diameter, four times the force must, in the former case, have to move eight times the mass; hence the

actual length of the vibration in the two cases must be the same, and the transverse action must be the same in both cases; for it depends entirely on the length of the vibration, without reference to the number of curves (Section 86). Again, calculated in diameters, the vibrations must be twice as long in the latter as in the former case, and the polarity produced consequently four times as great; but, the distance between the successive curves being four times greater in the latter than in the former case, the polar action of both must be the same. Again, the elemental or compound atoms which constitute a substance must evidently always be equal to each other; and, so long as the action is confined to the production of vibrations between these elemental or compound atoms, the same law must obtain. So long, therefore, as heat produces no change in the constitution of a substance, the vibratory action produced in each of the constituent atoms must be the same, whatever be the nature of the substance; and this accords with the law of specific heat.

74. When an undulatory force acts upon an elemental atom, its action upon the primary atoms of the interior must be reduced in proportion to the motion which it has produced on the atoms of the surface (Section 63); hence the motion produced by an undulatory force on the exterior primary atoms of an elemental atom must be greater than that on the interior atoms. As an undulatory force must act on both ends of the diameter of an elemental atom at the same instant, and in the same direction, it follows that, whilst at one end of the diameter the distance between the primary atoms is increasing, it must be decreasing at the opposite end of the diameter; but, when the distance is increasing up to a certain limit, the polarity of the atoms must be increasing; on the other hand, when the distance is decreasing, the polarity must be decreasing, and must become reversed if the distance is sufficiently decreased. If, then, the primary atoms at the opposite ends of the diameter were oppositely polarized or spherical before the action commenced, which would without

doubt be the case if the atoms were then absolutely at rest, the tendency of the action of the undulatory force must be to polarize them similarly, and thus to assimilate the polar action of two elemental atoms to that of two masses whose constituent atoms are similarly polarized to each other (Section 43), that is, to produce a repellent action of the different elemental atoms of a substance on each other.

When, however, the undulatory force is small compared with the force with which the primary atoms are combined, the increase and decrease of distance between the exterior and interior primary atoms may be so slight that it may be disregarded; and, as the force with which the elemental atoms are combined together must be much less than that with which the primary atoms are combined, the former must, in these circumstances, vibrate to and from each other precisely as simple centres of force.

75. This alternate increase and decrease of distance, or vibratory motion, between the primary atoms, must evidently be proportioned to the strength of the undulatory force acting upon the surface of the elemental atom; as, therefore, the undulatory force increases, the vibrations of the primary atoms must increase, also the repellent action on each other of the elemental atoms, and consequently the mean distance between them; that is, as the action of the heat increases the substance must expand.

Supposing the undulatory force still to increase, the repellent action of the elemental atoms must increase, and ultimately this polar action must become stronger than the attractive or gravitating force between the elemental atoms, and the distance between them must then, in that case, altogether depend on the pressure on the surface of the substance.

The amount of repellent action produced by an undulatory force must be inversely as the force with which the primary atoms are combined, and the amount of this force necessary to overcome the attraction existing between the elemental

atoms must be different in different substances; hence, at the same temperature, there may be substances in which these forces are acting in different proportions; and thus, under the same conditions, solids, liquids, and gases may be present.

76. It is evident that when the vibrations of the primary atoms are sufficiently strong to produce a preponderating repellent action between the elemental atoms, the vibrations of the latter must altogether cease. Hence, when an undulatory force of sufficient power acts upon a mass, it must first induce vibrations between the elemental atoms: these must rise to a maximum, and again decrease to nothing. But the decrease of the vibrations between the elemental atoms arises from the increase in the vibrations of the primary atoms constituting the elemental atoms; hence, whilst the undulations produced in the medium by the first-mentioned vibrations are decreasing, those produced by the latter must be increasing, the undulations actually produced in the medium must in these circumstances remain nearly constant, and, as measured by the thermometer, the undulatory force will apparently produce little or no result. The heat will appear to be absorbed by the substance, and rendered latent.

But, whilst the vibrations of the elemental atoms are decreasing, and those of the primary atoms increasing, the substance is passing from a solid to a liquid state; hence the result now described coincides, both in its nature and the circumstances which produce it, with what is generally called latent heat.

77. When the attraction between the elemental atoms of a mass has thus been counteracted, any increase of vibration between the primary atoms must be attended with a corresponding increase of temperature, provided the mass be prevented from expanding. If, however, the mass be allowed to expand, then the distance of the elemental atoms from each other, as also from a thermometer immersed in the substance, must increase; and the temperature, as shown by the thermometer, must, *cæteris paribus,* decrease as the square of this

increased distance. The action of the elemental atoms being now altogether repellent, there must, when the mass is in a state of equilibrium, be a pressure from without on all parts of its surface; and this pressure must evidently act as a force opposing the vibrations of the primary atoms. When, therefore, an increased undulatory force acts upon such a mass, and its expansion is prevented, the external pressure must be proportionally increased, and the vibrations induced on the primary atoms be less than if the mass were allowed to expand. For example, the pressure of the atmosphere remaining constant, a cubic inch of water at 212° is converted into about a cubic foot of steam; the polarity of the atoms of the steam must, in these circumstances, be 144 times greater than the polarity of the atoms of the water; for, as the pressure remains the same, the repellent action of the elemental atoms must remain the same, and the distance of these from each other is twelve times greater in the one case than in the other. The vibratory action of the primary atoms must also be 144 times greater; for their polarity is alternately nothing and a maximum. But a thermometer immersed in steam at the pressure of the atmosphere must be twelve times more distant from each atom than when immersed in water at 212°; consequently the measured temperature must be the same in both cases.

On the other hand, if the pressure had been so increased that the cubic inch remained a cubic inch, then the increase of vibration between the primary atoms would not have been so great as in the previous case; but, as the distance between the elemental atoms remains the same, the effect on the thermometer would be increased as these vibrations increased. Hence, if we compressed the cubic foot of steam again into a cubic inch, its temperature must increase, but, at the same time, the actual vibratory action of the primary atoms would decrease. If these views are correct, the term latent heat cannot be appropriately applied to the heat of vapours; if we said that when condensing steam we converted unavail-

able into available heat, we should more correctly describe the effect.

78. If the undulatory force acting on such a mass as we have been considering remained constant, whilst the pressure on its surface increased, the bulk of the mass would decrease, and the repellent action of the elemental atoms on each other increase; hence, although the actual vibratory motion of the primary atoms must decrease, this decrease cannot be sufficient to counteract the effects of the decreased distance between the elemental atoms, and the temperature must rise.

79. On the other hand, the undulatory force remaining the same, if the pressure on the surface were decreased, the mass would expand, and the repellent action of the elemental atoms would decrease; hence, although the actual vibratory motion of the primary atoms must increase, this increase would not be sufficient to counteract the effects of the increased distance between the elemental atoms, and the temperature of the mass must fall.

80. If, then, there be a substance in which the repellent action of the elemental atoms very slightly preponderates over their attractive action, which must be the case in liquids, and if the pressure on the surface be reduced, the upper film of the liquid must expand into a vapour, and its temperature must fall: what is now the surface of the liquid must be considered as to some extent immersed in the cold vapour, and its temperature must also decrease. If, then, the pressure be sufficiently reduced, and kept reduced for a sufficient length of time by the continual removal of the vapour as it forms, the repellent action of the elemental atoms on each other must so decrease that the attractive must become the preponderating force, and the remainder of the liquid, instead of expanding into a vapour, must condense into a solid.

81. The fact of the uniform velocity of light, and doubtless of all the other forces emanating from the atoms of matter, is a very natural result of the theory of emission, but appears, at

first, altogether opposed to that of a motion expanding through a medium equally in all directions from a centre. Yet, reasoning backward from the result to the source, we speedily arrive at a conclusion which renders it highly probable that this uniform velocity is as much the direct consequence of such a motion through a medium as it is of particles moving through a vacuum.

It can scarcely be doubted that, so long as the velocity continues uniform, the tension of a curve must continue uniform; that is, the distance between its constituent particles must remain the same, whatever be the distance from the centre. If this be so, the number of particles in a curve must increase as the square of the distance from the centre increases. As, however, the velocity of the curve does not suffer any proportionate diminution from the increase in the number of its particles, the total force in the curve must at the same time have received an increase; therefore these additional particles, when they joined the curve, must have been in motion in the same direction as the curve. This could only arise from one curve overtaking another, which could only happen when the curve overtaken had its velocity somewhat diminished, whilst the overtaking curve moved on unaltered, or with velocity more slightly diminished.

82. This last result is one whose occurrence is in the highest degree probable, if not inevitable; for, let A represent a curve emanating from the centre, when it reaches B it must set the particles in that circle in motion, whilst the particles in A come to rest; the force thus setting in motion a greater number of particles, its velocity must be proportionately diminished. But when a second curve emanating from the atom reaches B, it must only have to put in motion the particles left by the first curve, and must consequently continue to move with undiminished velocity, and must eventually overtake the first curve. Supposing it to do so when the first

Fig. 3.

curve was putting in motion circle C, containing twice the number of particles in A, then C would evidently be put in motion with the original velocity of the curve. Again, the curves moving toward the centre must carry back circles A and B to their former position, and, when again two consecutive curves emanate from the centre, the action must be repeated. Further, the curve composed of the first two combined curves must have its velocity decreased as it recedes from the centre, and be overtaken by the second combined curve, and so on, the result being, that the distance between the consecutive curves must increase as the square of the distance from the centre increases; and thus, although the tension of a curve remains constant, the force which, in a given time, impinges on a point must be inversely as the square of the distance of that point from the centre. The velocity of the force would, if acting as above described, suffer a continual decrease, the amount of which must depend on the distance between the consecutive curves. Considering that this distance is inconceivably minute, the velocity, practically speaking, must be uniform. A wave of light, in the time occupied in passing from Sirius to the Earth, would not, supposing this retarding cause removed, pass over an increased distance equal to its own length.

83. It is not, however, to be understood, that in the foregoing section any attempt has been made to indicate the precise steps by which this result is effected. The particles of the medium cannot be arranged in concentric circles round an atom as a centre, and hence, although curve A, in passing through the distance between A and B, must have its velocity as much reduced as would have been the case had the particles of the medium been so arranged, still this reduction must take place successively at different parts of the curve, not spreading regularly from any one point, as when two eccentric curves come in contact, but irregularly, one part falling behind, whilst the parts on either side move on for a time with undiminished velocity, the first curve thus falling back, part by

part, on the second. If, however, the different parts of the curve had received an increase of velocity instead of suffering a decrease, then, instead of two successive curves combining, the first curve would have been broken up into a continually increasing number of curves. This must be the case with the inward curves as they approach the centre; the number of particles in a curve must continually decrease; hence the velocity must increase. This taking place irregularly at different parts of the curve, as above described, some parts must move on in advance of the rest, until, their force becoming diffused through a greater space, their velocity again decreases, and they are overtaken by other parts of the curve, and the original curve thus becomes divided into two equal curves. This being continually repeated, the distance between the successive curves must constantly diminish as they approach the centre, the velocity remaining, practically speaking, constant.

84. It may be said that, as the curves are constantly falling back, part by part, one upon another, the force flowing to and from an atom cannot be considered as divided into consecutive circles, each separate and distinct from the other, on which consideration the argument has all along proceeded. But this objection loses great part of its force when it is remembered that, whilst the first curve is falling back upon the second curve, the third curve must be falling back upon the fourth, and thus, although neither the first and second nor the third and fourth curves can be considered as separate, the second and fourth must still maintain this character of separate and distinct curves.

Doubtless there are many objections which may be urged against these views, the whole reasoning upon them partaking more of the nature of suggestion than of demonstration; and as such I would wish it to be understood.

85. There can, however, be little doubt that such an action would have no effect upon the length of a wave of light. For, as the first curve falls back upon the second, the third upon the fourth, and so on, the effect of the action must be merely

to reduce the number of curves in a wave, the distance between the first and last curves of each wave remaining unaltered.

The effect of this process, constantly repeated, would be to increase the distance between the successive curves, until it became equal to the length of a wave of light, thus ultimately destroying the light. But, as we know the light is not so destroyed in passing through the immense space which separates the earth from the fixed stars, or still more distant nebulæ, the number of curves in a wave of light when it leaves the sun's surface must be beyond all calculation. This conclusion opens to us a view of the minuteness of the particles of the medium so extraordinary as to be at first sight scarcely credible; but the same result is arrived at whatever be the hypothesis, undulatory or emissary, on which we found our calculations.

86. Although the increase of distance between the consecutive curves must be attended with a corresponding decrease in the attractive, or repulsive, action of one atom upon another, it cannot be this that causes light to decrease as the square of the distance from its source increases. It has been shown (Sect. 64) that the transverse motion of a curve must depend on the distance travelled by the atom between the emanation of two curves. If, then, we suppose that, whilst the atom is moving through that distance, a great number of curves emanate from it, the total transverse motion would not be increased thereby; because, according as the number of curves increased, the distance travelled by the atom between the emanation of two curves would decrease, and the transverse motion of each curve also decrease in the same ratio. When, therefore, the time occupied by the atom in moving over a certain space remains the same, the total transverse motion of the curves must remain the same, without reference to their number. When, therefore, the number of curves in a wave decreases as the square of the distance from the centre increases, the transverse action of the wave does not so decrease; because, as the curves decrease in number, their transverse action increases;

for the distance between the centres of the outward and inward curves is thus increased.

87. When S vibrates from *c* to *d*, there are no transverse motions in the ray *c d*; but, as the divergence of the ray from S C decreases, the transverse action increases, reaching a maximum in the direction S: S C is therefore a ray of maximum force. The strength of the transverse action in a beam of light must therefore depend on the distance between the rays of maximum force which it contains; that is, the quantity of light in a beam must be inversely as the square of the distance between the rays of maximum force. When a body is radiating light, its atoms must be vibrating in all possible directions, each point of its surface being a centre whence the rays emanate in all directions; hence, so far as the ratio of decrease in the transverse action is concerned, the effect must be the same as if the atoms all vibrated in the direction of the surface, and the rays of light radiated from the common centre of the body. Hence the distance between the rays of maximum force must increase in each direction as the distance, and the light decrease as the square of the distance, from its source.

88. When, however, a beam of light, R S, the constituent rays of which are parallel, is incident upon a body R, the vibrations excited in the atoms of R must be all transverse to R S; hence the rays of maximum force thus produced must be all parallel to each other, and the resultant beam must, unless acted on externally, continue of the same strength at all distances from the centre. Thus, although a ray of light transmitted through, or reflected from a body, has its origin in vibrations excited in that body, its strength is not necessarily inversely as the square of the distance from the body, but the ratio of its decrease depends entirely on the divergency of the rays of the incident beam; the light thus produced decreasing exactly as the incident beam would have done had it not been intercepted. Hence, also, if the transverse motions thus produced interfere with, and destroy, the

effects of the incident beam as it passes through R, they must continue to do so at all distances from R.

89. Hitherto the transverse action of a curve has been supposed to arise from a body vibrating between two points; but, if the body were to move only in one direction, the transverse action of the curves would not cease. As, however, this action in opake bodies is confined to the surface, it can only act on the atoms in one hemisphere of an opake rigid sphere, and would not therefore produce a motion of the sphere as a whole in the direction opposite to that in which the origin is moving, but would cause the sphere to rotate on its axis. But when S (fig. 1) rotates on its axis, all the atoms in the inner hemisphere *c* C *d* must be moving constantly in one direction, and the result must be a rotatory motion of R, the inner hemispheres of S and R moving in opposite directions.

90. The sun being a sphere rotating on an axis, a rotatory motion of the planets ought, according to the foregoing reasoning, to be the result. The direction of the rotation of the sun and planets agrees with this view of its origin, and calculation produces a period of rotation very closely coinciding with that of observation.

91. In considering the transverse action of a vibrating atom, the length of the vibration *c d* was considered as a mere point in comparison with the distance R S, and the attraction of S for R as constantly exerted in one line, and the transverse action of the curves as consequently unopposed. If, however, the distance R S be sufficiently diminished, a point must be reached when this must cease to be the ease. Two forces must then act upon R; one the transverse action of the curves, the other arising from the change of direction in which S attracts R. When the former force tends to produce a motion of R toward *c*, the second must tend to produce a motion toward *d*, and the direction in which R moves must be the resultant of these two motions; but, considering S as a single atom, whilst the transverse action remains the same at all distances, this second force, which may be called tangential,

must depend on the angle $c\,\mathrm{R}\,d$, and may be considered as inversely proportioned to the distance; and so far, therefore, practically speaking, the transverse action of the curves may, within certain limits, be considered as increasing as the distance increases. Again, considering S as a spherical mass, the transverse action of the curves, as well as the tangential force, must decrease as the square of the distance; but, as dependent on this, the rotatory velocity must remain unaltered; for transverse force $(\frac{1}{r^2})$ divided by tangential force $(\frac{1}{r^3})=r$ =distance from the sun, provided this distance does not exceed a certain limit. Hence the actual rotatory velocity produced must be directly as the square root of the distance. Beyond this limit the rotatory velocity must increase more slowly, at a further distance cease to increase; and when the sun appears a mere point, the transverse action must be unopposed, and the rotatory force must decrease as the square of the distance increases. Hence, supposing the fixed stars to rotate, they cannot influence the rotation of the planets; further, from the very small angle which the planets must subtend when seen from each other, their mutual rotatory action must be so small, that it may, perhaps, without much error, be disregarded.

92. Although the force producing rotation is constant in its action, the velocity produced must be uniform, and not accelerated. In Section 21 it has been shown that the force flowing from and to the sun must retard the motions of the planets in their orbits; it is evident that the same action must retard their rotatory motions. This retarding action decreases as the square of the distance; hence, when the distance is so great that the rotatory force may be considered as decreasing in the same ratio, the velocity produced would be the same at all distances from the centre, were there no other forces in operation. But the atoms of a rotating planet must be retarded by the forces flowing from and to its centre, precisely as the planets are retarded in their orbits by the force of the sun; and, as this retarding action must be the same whatever be the distance from

ERRATA.

Page 52, line 9, *for* $\left(\frac{1}{2\,2}\right)$ *read* $\left(\frac{1}{r^2}\right)$; for $\left(\frac{1}{2\,3}\right)$ *read* $\left(\frac{1}{r^3}\right)$.

Page 53, line 19, *for* increased *read* measured.

the sun, the actual rotatory velocity must, in the above circumstances, decrease as the square of the distance increases. Hence this retarding action of the sun's force, though partly neutralizing its transverse action, does not alter the proportionate rotatory velocities of the planets. Again, the retarding action of the atoms of a planet on each other must increase with the velocity, and must therefore ultimately neutralize any accelerating force, however great; and the velocity of rotation must therefore in all cases be uniform, and measured by the transverse action of the sun; that is, within certain limits, increase as the square root of the distance from the sun increases.

The velocity of rotation so produced must be also uniform at all points of the planet's orbit; for the velocity of a planet at different parts of its orbit is inversely as the radius vector. Thus, if $\frac{1}{\sqrt{p}}$ be the velocity of a planet in its orbit when at perihelion, then $\frac{1}{\sqrt{a}} \cdot \sqrt{\frac{p}{a}} =$ velocity at aphelion: the loss of velocity caused by the planet's divergence from a circular orbit is thus increased by $\sqrt{\frac{p}{a}}$. The same expression must also represent the loss of rotatory velocity thus caused; hence, at aphelion the velocity of rotation must be equal to $\sqrt{a} \cdot \sqrt{\frac{p}{a}} = \sqrt{p}$; that is, be the same at all points of an elliptic orbit.

93. As the planets do not rotate in the plane of the sun's equator, it must be necessary, in calculating the periods, to take into consideration the different inclinations of their axes. Let r be the distance from the sun, p the period of rotation, θ the inclination to the ecliptic. Then, taking the earth as the basis of the calculation, $\frac{r^{\frac{1}{2}} \cdot \cos^2\theta \cdot p \text{ of Earth}}{r^{\frac{1}{2}} \cdot \cos^2\theta \text{ of Planet}} \times \frac{1}{0{\cdot}889} = p$ of Planet. Hence

	Calculated period.	Observed period.
Mars	24 hours 37 minutes	24 hours 37 minutes
Jupiter . .	9 ,, 57 ,,	9 ,, 56 ,,
Saturn . .	10 ,, 3 ,,	10 ,, 29 ,,

The only difference calling for observation between the observed and calculated periods is in the case of Saturn; and the presence of the rings perhaps renders the case of this planet exceptional,—although, considering them as rigid substances, it is not easy to see what effect the rings could produce; for when their plane passes through the centre of the sun, the period of rotation should be the calculated period. Further, the rotatory action of the sun on the rings and planet at different points of the orbit can, I think, very slightly vary; for, whenever the illuminated surface of the rings exceeds the shaded surface of the planet, more than a hemisphere of the former must be acted on, and the rotatory action on this excess must neutralize an equal rotatory action on the other hemisphere. If we consider the rings as so constituted that the transverse action does not produce a movement of them as a whole, but merely a movement of their constituent atoms among themselves, we must consider the planet as having to drag the rings after it as it rotates, and its velocity as reduced accordingly. The fact that the period of rotation is longer in the case of the rings than in the case of the planet, and that the period of the former corresponds with what would be the period of revolution of a satellite at the same distance, gives some grounds for this supposition; but the question I must leave to those better able to elucidate it than I am, whose knowledge of astronomy is confined to a little desultory reading. As, however, the rings must increase the quantity of force flowing to and from the centre of the planet, they must thus (Section 92) retard the planet's rotatory velocity.

The inclinations of the axes of the other planets are not given in any work I have seen: those of the inferior planets are said to be very great. In their case, therefore, calculation

and observation differ very widely. Astronomers, however, appear to differ very much regarding the period of rotation of these planets,—some, according to Sir John Herschel's "Outlines of Astronomy," contending for a period twenty-four times that usually given. It may be observed that, were the axis of Venus inclined about 72°, and that of Mercury 67°, calculation would give a period nearly ten times that usually given.

94. The periods of rotation of the satellites point to the conclusion, that, within a certain distance, bodies revolving round a central body always rotate in a period coinciding with that of revolution. It is evident that, within a certain distance, the transverse action must be so slight that it may be disregarded. What most probably gives to the rotation of the satellites its peculiar character is, that, owing to their proximity to their primaries, the attraction of the latter must be sensibly greater on the nearer than on the more remote parts of their inner hemispheres: thus, the attraction of S for the point A of R must be greater than the attraction for the points *a* or *b*. Hence, as R revolves round S, this unequal attraction must act as a force retaining A in its position, as the point nearest to S. This view of the case is by no means novel, though it has not met with much approval from astronomers; yet there can be little doubt that the force has a real existence, and must act as described. The period of rotation so produced can never be shorter than that of revolution, though it may be longer. Taking the moon's average distance from the sun as coinciding with that of the earth, the period of rotation produced by the sun would be about $22\frac{3}{4}$ hours. The action of the sun on the moon's rotation must thus be always accelerative; but, as its action is confined to the surface, whilst that of the earth is not, the latter must be by far the stronger. It is improbable that the period of rotation so produced can be shorter than that of revolution, though doubtless the sun's action may prevent its being longer. Whether a uniform rotatory velocity would thus be produced, does not, however, appear.

95. In the formula in Section 93, a constant quantity, equal to $\frac{1}{0 \cdot 889}$, has been introduced, without any reason given. If, however, instead of taking the earth as the basis of our calculation, any of the other planets had been taken, then, so long as we were thus calculating the rotation of the earth, this constant quantity would remain, but would require to be expunged from the formula whenever any of the other planets became the subject of calculation. Hence, if these views be correct, there must either be a force accelerating the rotation of the earth which does not act on any of the other planets, or the observed periods of the latter cannot be the true periods. Would not the inflection of light produce an effect analogous to this? Let the sun, the planet, and the spectator be all situated in one line; then, during one-half of a vibration, $g\,g'$ would be the hemisphere on which the outward force of the sun would impinge; and the outward force of the planet impinging on the sun would be the force emanating from $g'\,g$; during the other half of the vibration it would be the force emanating from $h'\,h$. Hence the portion of the planet actually seen by the spectator would be the arc $h'\,A\,g'$, for light would be reflected from the arcs $b\,g$ and $a\,h'$, as well as from $a\,A\,b$, Section 68, and a spot would therefore be visible during more than one-half of a revolution: further, in all positions of the spectator, the illuminated surface would thus be increased. Whether the inflection of light would render visible an arc of about 10°, is what I have no means of determining.

96. Referring to Section 91, as S rotates on its axis, each atom on its surface draws each atom of the surface of R toward it, and would thus, while attracting the atoms of R toward S, also impress on them a motion in the same direction in which it is itself moving, were this latter action not counteracted by the transverse action of the curves. But the transverse action of the interior atoms of S must be neutralized by their action on the other interior atoms, Section 102, and these atoms must consequently act as above described on the atoms of R.

Further, this motion, being in the same direction in which the atoms of S are moving, cannot be confined to the surface of R, but must act on every atom of R, and the result, therefore, be a motion of R as a whole tangential to S, and in the same direction in which S rotates. The atoms in hemispheres *c* C *a* and *d* D *c* of S moving in opposite directions, the force of this tangential action must be measured by the excess of attraction of the atoms in the former hemisphere for R, and must therefore decrease as the cube of the distance; but, as it must also decrease as the angle *c* R *d*, this tangential action must be inversely as the fourth power of the distance.

In treating of the action of the sun upon the planets, we generally reason as if the whole force of the sun emanated from its centre,—that is, as if the sun were a single atom,—and, so reasoning, it is impossible that the idea of this tangential action can arise; but if, instead of considering the sun as a whole, we consider the action of each atom separately, it is evident that it may be resolved into two,—one toward S, and one tangential thereto. The resultant of all the former must be toward the centre of the sun, that of the other tangential to the sun's radius, and in the direction in which it rotates. This tangential force thus acts in the same direction as the projectile force of the planets.

97. This latter is generally supposed to be the effect of an impulse impressed on the planets at their creation; but, unless they move through an absolute void, this is impossible; for, whether we proceed upon the theory of emission or of a medium, we find the same necessity for a force acting tangentially to the sun's surface, and operating as constantly as gravity itself; otherwise, in consequence of the retarding action described in Section 21, the velocity of the planets would constantly decrease. As this retarding action increases with the velocity, it must ultimately equal, but can never exceed, any accelerating force, however great. Again, because it is inversely as the square of the distance from the centre, whilst the tangential force, acting in the opposite direction, is in-

versely as the fourth power of the distance, the former may be considered as the same at all distances from the centre, and the latter as inversely as the square of the distance from the centre. Hence, when these two forces neutralize each other, the tangential velocity must be inversely as the square root of the distance from the centre; and all the planets, as thus acted on, must revolve in their orbits as if the retarding and accelerating forces had ceased to act; that is, as if the planets had been projected into an absolute void, and moved on uninfluenced by any force except that of gravity. (*See note.*)

98. But, besides the retarding action described in Section 21, there is another, not dependent on any particular theory of gravity, but on what we can scarcely doubt must be the fact, viz. that gravity cannot emanate from one atom and impinge on another at precisely the same instant, but that, as in the case of light, a certain period of time must elapse between the two events; and thus the direction in which one atom attracts another is not necessarily that of the position which it at that moment occupies, but that of the position which it occupied when the force emanated from it.

If R move in the direction R B, and S in the direction S C, with the same velocity, then a curve emanating from S, when the atom occupied the position S, may impinge on R when at B; the distance from which S acts upon R being thus increased. On the other hand, a curve emanating from R, when at R, would impinge on S when at C, and the distance from which R acts upon S be thus decreased. But if R and S be two atoms of a mass, then, before motion commenced, the attractive and repulsive forces acting upon the atoms must have been equal; hence, as the repulsive action decreases with an increased distance, the attractive action toward X must, in the case of R, overcome the repulsive, whilst the repulsive action from X must, in the case of S, overcome the attractive, and the result be a retardation of the motion of the mass.

On the other hand, it is only the nearer atoms of a mass that repel each other; the further atoms attract each other.

This attractive action decreasing with increased distance, the attraction on R toward X must be diminished, whilst the attraction of S is increased, and this must be equivalent to an acceleration of the motion of the mass. Hence the effect actually produced must be accelerating or retarding according as the change in the repulsive or attractive actions preponderates. It is evident that if the distance between the atoms of a gas be increased, the decrease of repulsion must be much less than when the distance between the atoms of a solid is increased in the same proportion. We may probably, therefore, consider this action as retarding in the case of solids, and accelerating in the case of liquids and gases. As this retarding or accelerating action must increase as the square of the velocity, practically speaking, it must, in the case of the planets, be inversely as the square of the distance from the sun, and, therefore, cannot affect the conclusion arrived at in the preceding section.

99. The transverse action, although acting only on the surface of planets, must, as its action is not at all points tangential to the planet, act to some extent as a force retarding their velocities; and this retarding action must, in proportion to its force, disturb the state of equilibrium described in Section 97; for, whilst the tangential velocity is inversely, the transverse action is directly as the square root of the distance. Hence, supposing that at its mean distance from the sun the retarding and accelerating actions on a planet are equal, and its velocity precisely what experience shows it to be, as it moves toward perihelion, the distance from the sun diminishing, the retarding action of the transverse force must diminish, and an accelerating action thus preponderate, until the mean distance is again reached, and in this part of its orbit the velocity of the planet should therefore increase more rapidly than the square root of the distance decreases. As the planet moves toward aphelion, the transverse action must increase, and a retarding action preponderate, until the mean distance is again reached. In the case of planets, however, this variation of velocity must

be so very slight as to be quite inappreciable; for, in the first place, the transverse action acts only on the surface, and only half of its force can be considered as retarding; it must therefore form such an incalculably small part of the total retarding action, that, even were it altogether to disappear, the increase of projectile force would be too slight to be perceptible. Further, the action described in Section 98 being retarding in the case of rigid bodies, and increasing with the velocity, it follows that if, as a planet moves from its mean distance to perihelion, the velocity increases more rapidly than the square root of the distance decreases, this retarding action must increase more rapidly than the tangential force; and hence the acceleration produced by the decrease of the transverse force must be to some extent neutralized by the increase of the retarding action resulting from the progressive action of gravity. The actual effect produced, therefore, must depend on the strength of this latter action, and, although all increase of velocity cannot thereby be perfectly prevented, practically speaking it may be so, for it may be reduced below any assignable amount.

100. In the case of comets, however, the result must be altogether different, for, being to some extent transparent, the transverse action cannot be confined to the surface nearer the sun, but must penetrate the mass of the comet, and its action be therefore altogether retarding. Not being rigid bodies, the action described in Section 98 must probably be accelerating, and the effect produced therefore depend on the sum of these two actions, and not on their difference, as in the case of planets. The precise effect of this action on a comet's orbit I must leave to others to determine, but, being accelerating at perihelion, and retarding at aphelion, the result must be an orbit of great eccentricity. This gives rise to a curious speculation. It is only within certain limits that the transverse action increases with the distance; beyond that limit it decreases. If, then, the aphelion point of a comet's orbit reach a sufficient distance from the sun, the action may be accelerating both at perihelion and aphelion, and this would termi-

nate in the eccentricity of the orbit again decreasing, and the perihelion distance increasing; the retarding action thus increasing, ultimately the aphelion distance would cease to increase. If, then, the total accelerating and retarding actions at different points of the orbit were equal, the perihelion and aphelion distances might perhaps be considered as constant. Would not the orbit be, in such circumstances, in a state of unstable equilibrium? For, supposing a retarding action to act for a time as the comet moves toward aphelion, the distance of this point would be diminished, and, the accelerating action being also thus diminished, when again the comet completed a revolution, the aphelion distance would be still further diminished, as also the total accelerating action. The retarding thus becoming the preponderating action, the period of the comet and its mean distance from the sun would constantly diminish, until, at a certain distance, the accelerating would again equal the retarding action, the eccentricity increasing. If, then, the acceleration arising from the decrease of perihelion distance increase in a higher ratio than the decrease of velocity arising from the decreased aphelion distance, the distance of this latter, and the period of the comet, would again rise to a maximum, and the variations in a comet's orbit thus be periodical. This speculation is probably one which calculation may show to be baseless, but comets are subjects on which it is notorious that romancing is allowable even to philosophers.

These views lead to at least a partial explanation of some of the peculiar appearances of comets. As they approach the sun, the accelerating and retarding actions must be pressing on them with immense force, and this pressure, being tangential, or nearly so, to the sun's surface, must elongate a mass of such slight density as a comet in the direction of the sun's radii; further, the matter of the comet must be pressed from the sun, because the pressure must decrease with an increased distance.

101. The retrograde motions of certain comets and of the satellites of Uranus, and the inclination of the orbits and axes

of many of the heavenly bodies, may be taken as evidence that there are other forces acting on them besides those above treated of; such force or forces being probably at a minimum in tho plane of the sun's equator, and increasing with the inclination thereto. That the tangential force must decrease with an increase of inclination is evident, but the cause of the opposing force does not appear, for the transverse action should also decrease with an increase of inclination.

102. If the reasoning in Section 91 bo considered as sufficient to demonstrate that the rotation of the planets is caused by the rotation of the sun, we must admit other consequences of that rotation, raising the question, whether it may not be that from these consequences result the light and heat of the sun.

For, let C *c* D *d* represent the sun, then atoms C and D must move with equal velocities in opposite directions. In the outward curve emanating from D, the transverse motion in the ray D C must be equal, and opposite to the transverse motion in the ray C A of outward curve C. If, then, the effects of the transverse motion in the ray D C are not destroyed by opposite transverse motions in its passage through the sun, the rays D C and C A must interfere, and the rotation of the planets could not arise from the rotation of the sun. But if we hold the reverse to be proved, outward curve D must, when passing through the sun, impress on some of the atoms therein a motion, in a direction opposite to that of its source, sufficient to counteract the effects of its own transverse motion, —a conclusion which in itself is highly probable. Similarly, that part of outward curve C which passes through the sun must impress on some of the atoms therein a motion contrary to that of C, and also every ray emanating from an interior atom must impress on some of the other atoms a motion contrary to that of its source. When, then, two opposite rays act on the same atom, they must do so at different times; otherwise no motion, and consequently no interference, would take place, and thus a vibratory motion of the atom be produced.

But when an atom vibrates in this manner it must communicate a vibratory action to the adjacent atoms, and thus there would be propagated, throughout the whole sphere of the sun, a vibratory motion of its atoms, the result of which must, at all events, be the production of heat.

Considering the comparatively slight velocity of the atoms in the sun arising from rotation, it seems improbable that the vibrations thus produced can be sufficiently rapid to produce light; but, though these vibrations may not themselves be luminous, their combined action on another body might give rise to luminous undulations; and this would agree with the views of those astronomers, regarding the constitution of the sun, who hold that the source of the sun's light is that peculiar atmosphere which appears to surround it, and that the sun itself is a dark body.

Whether the cause stated is sufficient to produce such great effects is what I cannot determine; but there can, I think, be little doubt that from the rotation of the sun and planets there must arise a vibratory action of their constituent atoms, producing heat to some extent in them all; and we ought perhaps rather to look to the rotation of the earth for the cause of its internal heat, than to a gradual cooling from a past state of fusion; a speculation, which has always appeared to me exceedingly fanciful, and highly inimical to the existence, at a future period, of organized matter.

103. If the reasoning in Section 84 be correct, the distance between the consecutive inward curves of force continually decreases as they approach the centre; this distance may therefore at last disappear, and the result be a solid mass. The form of such a mass would evidently depend on the form of the inward curves, and it would therefore possess all the properties of an atom of matter, as defined in Sections 6 and 10. Hence it results that the particles which constitute an atom of matter may be identical in kind with those which constitute the medium, and that there thus may be only one description of matter in the universe.

104. Reverting, again, to the consideration of light. Thc undulations of the different eolours being each of a determinatc length, and the shortest being nearly three-fifths of the length of the longest, it follows that, if light be produced by the vibrations of the elemental atoms of a body, it ean scarcely be produced by the vibrations of the primary atoms to and from the centre of the elemental atoms, for these latter vibrations must evidently be performed in a time very mueh shorter than that of the former. This eoincides with the faet that air, however highly heated, never beeomes luminous ; for, according to Seetion 76, when a substance exists as air, it is only the primary atoms whieh vibrate. Possibly the transpareney of air may arise from the same eause, the vibrations of the primary atoms being too short to interfere with the eomparatively long undulations of light.

105. The elemental atoms of even the most homogeneous bodies being grouped together into erystals, and there being little doubt that the attraetion between the eonstituent atoms of sueh erystals must be greater in some direetions than in others, it follows that the rapidity of the vibrations of the elemental atoms of a crystal produeed by an undulatory force, may depend on the inelination of the ray to the line or lines of greatest attraetion ; and, as the different erystals in a mass ean seareely be so arranged that these lines are all parallel, it may be that herein lies the explanation, why, although all aeted on by the same foree of heat, some of the atoms may vibrate more rapidly than others, thus produeing luminous undulations of all the different lengths.

CHAPTER V.

ON ELECTRICITY, ELECTRIC CURRENTS, AND MAGNETISM.

106. According to Section 69, when an atom vibrates to and from its mass, it is alternately similarly and oppositely polarized thereto, its polarity, in such circumstances, depending on the polarity of the mass. But if, when the vibrating atom commenced its return, it had been more strongly polarized than the non-vibrating atoms of the mass, it would have been the polarity of these latter that would have changed (Section 49), the former vibrating to and from the latter with a polarity alternately increasing to a maximum, and decreasing to a minimum, but remaining always of the same kind. This peculiar action would evidently take place if the atoms A (Section 58), instead of combining, had again separated and returned to their respective masses; for, although their polarity would decrease when they approached each other very closely, it would again rise to a maximum as they separated (Section 53); the polarity of the atoms thus not depending entirely on the polarity of the non-vibrating atoms of the mass.

But, in order to produce any practical effects, it would be necessary that the atoms should approach and recede from each other a great number of times with great rapidity. This takes place when two different substances are rubbed on each other, for each atom of the one surface must alternately approach to, and recede from, each atom of the other; and, considering the minuteness of an atom of matter, it is evident that, with even a very slight velocity, each atom must thus be acted on an innumerable number of times in a single second.

107. The atoms which thus vibrate to and from each other cannot be the primary atoms; they must either be elemental or compound atoms. The production of polarity on the atoms A,

by their mutual action, depending entirely on the convergency of those rays of the inward curves of the one which impinge on the other, the primary atoms forming the inner hemispheres of two elemental atoms must, when they approach very closely, be more strongly polarized than the primary atoms which form the outer hemispheres. Hence, when the atoms A return to their respective masses, the hemispheres which form the surfaces of the masses must be more strongly polarized than the others, and the polar action of the masses must depend on their surfaces.

Let this excess of polarity on the exterior hemispheres of the elemental atoms forming the surface of a body be called free polarity.

108. When two elemental atoms approach each other so closely that their hemispheres become unequally polarized, let the action be termed conduction; but so long as the polarity is equal on both hemispheres, let the action be termed induction.

109. Suppose one of the masses at rest, and the other rubbing on its surface, each atom in the surface of the former must move toward the atom approaching it, and follow it for a time as it again recedes; the central point of the exterior hemisphere or pole, being always directed to the approaching and receding atom, must thus describe the segment of a circle, and the motion of the atom may be decomposed into two—one perpendicular to, and one in the direction of the surface, exactly as in Section 69.

The free polarity of the surface not being uniform, but alternately increasing to a maximum and decreasing to a minimum, the polarity of the curves must also vary; and such a body must therefore be a centre from which is emanating a series of polar undulations.

110. In this chapter I shall attempt to show, that exactly as the uniform action of the spherical curves emanating from an atom produces gravity, and their vibratory action light, so, in an undulating polarity, lies the cause of electricity, and in a constant polarity, that of magnetism.

111. When free polarity is produced on one part of the surface of a body whose atoms are free to approach each other sufficiently closely to produce conduction, the polarized atoms must, in consequence of the vibration described in Section 109, act on those adjacent to them, first oppositely polarizing and attracting, then similarly polarizing and repelling them. These atoms must act similarly on those adjacent to them, and free polarity of the same kind be thus excited over the whole surface of the body. In all probability, however, the atoms must separate from each other before absolute repulsion takes place, because, when the attraction between them becomes very weak, the attraction of the other atoms of the surface must probably become the preponderating force; but, as shall be made evident in Section 112, the ultimate result must be the same in either case. As, when a polarized and a spherical atom approach each other very closely, the effect of the action on the former is to reduce its polarity to the same extent that the other has become polarized, the polarity of the originally polarized atoms is therefore weakened by acting on those adjacent to them; and, as the polarity of these in their turn is weakened by acting on those adjacent to them, they must be again acted on by the originally polarized atoms, and thus, ultimately, the free polarity must be diffused equally over the whole surface, the strength of the polarity on each atom being to that originally excited as the extent of surface originally excited is to the whole surface; the action thus coinciding with that of an elastic fluid diffusing itself over the whole surface.

112. When the polar undulations emanating from a body polarized as described impinge on another conducting body, the action, coinciding to some extent with that of heat, must produce a vibrating polarity in the atoms of that body. But, unless when brought very close together, no free polarity can be directly produced, for the polarizing action of the former body must evidently be equal on both hemispheres of the constituent atoms of the latter.

Let S, figure 1, be a body in which polar vibrations have been excited, and R a conducting body in its natural state. If the polarity of S be negative, positive polarity must be induced on R, the positive poles of the polarized atoms pointing toward S. A vibratory motion of the atoms being also produced, atoms *b* and *h* must approach each other; when they do so very closely, their polarity must decrease (Section 48), and, being elemental atoms, the polarity of their inner hemispheres must decrease more rapidly than the polarity of their outer hemispheres, and thus free positive polarity must be induced on the hemisphere of *h* nearer S, and free negative polarity on the hemisphere of *b* further from S. When *h* and *b* are thus approaching each other, *g* and *f* must also be approaching each other with similar results,—free positive polarity being induced on the hemisphere of *g* nearer S, and free negative polarity on the hemisphere of *f* further from S. The atoms, however, cannot continue to approach till absolute repulsion takes place; for, before this happens, the attraction between *g* and *b* must become the preponderating force, and these atoms must separate from *h* and *f*, and approach each other. The force with which they do so must be greater than that with which *b* and *h* approached, for, in addition to the inductive action of S, there is now the free polarity of their inner hemispheres; hence *g* and *b* must approach very closely, and the free polarity on their inner hemispheres become neutralized, and free positive polarity be produced on the hemisphere of *b* nearer S, and free negative polarity on the hemisphere of *g* further from S. The attraction between *g* and *b* thus becoming reduced, the attractions between *b* and *h*, and *g* and *f*, must again preponderate, and these atoms must again approach each other with the same results as before. Free positive polarity must thus accumulate on the end of R nearer S, and free negative polarity on the other end of R. This accumulation of free polarity must go on until the consequent mutual repulsion of the atoms on the further end of R counterbalances the action of S on its nearer end. The effect of

this action must evidently be to produce polar attraction between the two bodies. If, while R and S were still at some distance from each other, the action of S had ceased, the free polarities on the opposite ends of R would have diffused themselves over the surface (Section 111), and, being equal, would have neutralized each other.

113. If the action of S had continued until the bodies had approached each other very closely, conduction, and consequently repulsion, would have taken place, R becoming negatively polarized, and the free polarity on S to an equal extent reduced.

114. If there be a third body, P, as in the figure, R must act on P precisely as it is itself being acted on by S. If, then, P approach very closely to R, conduction must take place, P becoming negatively polarized, and the free negative polarity on R to a corresponding extent reduced. P and R must therefore repel each other, and, if the action of S afterwards cease, the free polarities on R must diffuse themselves over the surface, but, there being now an excess of positive polarity, the surface must remain positively polarized.

115. If R, instead of being in its ordinary state, had been polarized with free positive polarity, then the mutual action of the nearer ends of S and R would have increased the vibrations of the atoms in the direction R S; the proportional length of the lateral vibrations would thus be decreased, the tendency of the action being to cause the positive poles of the polarized atoms on R to point toward S.

The atoms thus vibrating in the direction R S, atoms *b* and *h* must approach each other; as they do so the polarity of their inner hemispheres must decrease more rapidly than that of the outer hemispheres; and thus the free polarity on *b* would be either wholly or partially neutralized, whilst the free polarity on *h* would be to an equal extent increased.

Similarly, atoms *f* and *g* must have been approaching each other, the result being the complete or partial neutralization of the free polarity on *f*, and a corresponding increase of that

on *g*. As in the previous case, the mutual attraction between *b* and *g* must eventually preponderate, and *b* and *g* must approach each other. As they do so, the polarity of their inner hemispheres decreasing more rapidly than that of the outer hemispheres, the free polarity on *g* must be neutralized, whilst an equal quantity of free positive polarity is produced on the hemisphere of *b* nearer S; the attraction between *b* and *g* must in consequence decrease until the attraction of *b* for *h* and *f* for *g* again preponderates, when *b* and *h*, and *g* and *f* must again approach each other with the same result as before; and the ultimate result must thus be exactly the same as if the free positive polarity on R had been an elastic fluid, drawn by the attraction of S from all parts of R to those parts of the surface nearest to S. Any further action of S upon R, after the further end of the latter has been completely depolarized, must evidently result in the development of free negative and positive polarity at the opposite ends of R, as in the previous case.

It need scarcely be observed that R must act in a similar manner on S, and that such an action must be attended with an increase of attraction between the bodies.

116. If R and S were similarly polarized, they would repel each other. Further, as this repellent action must decrease the vibrations of the atoms in the direction perpendicular to the surface, thereby increasing the proportional strength of the lateral vibrations on the nearer ends of the two bodies, whilst its action on the further ends would be precisely the reverse, the tendency of the action must be to cause the freely polarized poles of the atoms to point toward the further ends of the bodies, and thus, reasoning as in the preceding section, to accumulate the free polarity on the parts of the two bodies most remote from each other.

117. Conduction, according to the foregoing reasoning, consisting in such a close approach to each other of the elemental atoms that the polarizing action on the primary atoms of the inner hemisphere is greater than that on the primary atoms

of the outer hemisphere, it is evident, if the reasoning be correct, that the conducting power of different bodies depends on the nearness to which, under similar circumstances, their constituent atoms can approach. If, when at their least distance, the atoms be so far separated that the polarizing action on both hemispheres is equal,—that is, practically speaking, equal, for it can never, in such circumstances, be absolutely so,—such substance must be a non-conducting substance, and would not be attracted by an electrified body, for no free polarity could be induced upon it*.

118. The atoms of all bodies being in a constant state of vibration from the effects of heat, there may be a constant production of electricity in all bodies; for, when the atoms are at their least distance from each other, the inner hemisphere of the atom whose polarity changes may be more strongly polarized than the other, whilst the outer hemisphere of the atom whose polarity does not change may be more strongly polarized than the inner. In such a case there must be equal quantities of free negative and positive polarity produced, but, as there is no force in action to cause the opposite polarities to accumulate on different parts of the body, they must counteract each other's action; and there can be little doubt that whatever free polarity is thus produced must be immediately neutralized. If, however, one part of a conducting body were more strongly heated than another, and the colder parts of the body were connected by a conductor, an electric current would be produced, the action coinciding with that to be described in Section 123.

119. If two bodies, on whose surface free polarity of opposite kinds has been excited, are separated from each other by a non-conducting substance, their mutual action on the atoms

* According to the above, every substance must be to some small extent conducting. A non-conductor, when acted on by an electrified body, may therefore be considered as an absolutely non-conducting mass, having a film of conducting matter attached to that part of the surface nearest the electrified body.

of the non-conductor may be so powerful as to cause them to approach each other so closely as to produce conduction, when the opposite polarities on the two bodies would immediately neutralize each other. It is evident that such a result could only be effected by a sudden and violent disturbance of the arrangement of the atoms in the non-conductor. This result so far coincides with the fact of electrical discharge, but it does not explain how such discharge can take place through a vacuum; for, according to the preceding reasoning, the opposite polarities could only neutralize each other, in such circumstances, by an approach of their surfaces within conducting distance. The experiments on this subject can scarcely, however, be accounted crucial, as it is doubtful if an absolute vacuum has ever been obtained, whilst a mere rarefaction of the air, by weakening the repulsive action of its atoms on each other, would rather facilitate the action on it of the vibrating polarity*.

120. When polar vibrations have been produced in the atoms of a conducting body, and the exciting cause has ceased to act, the atoms of the body, if otherwise unacted on, must almost instantly return to a state of rest; but, if they act, and are acted on inductively by other bodies, this mutual action must sustain the polar state. Thus, air being a non-conductor, an electrified body must act inductively on the atoms of the atmosphere nearest it, and the action thence arising must maintain the polarity of the atoms of the body precisely as if electricity were an elastic fluid retained on the surface of the substance by the pressure of the atmosphere.

121. Heat, like electricity, is caused by vibrations of the polarity of bodies; but bodies conduct heat very slowly compared with the velocity with which they conduct electricity. This, perhaps, may be accounted for by the action of electricity being strictly confined to the surface, whilst heat acts on

* Since the above was written, I have seen in a magazine a short account of some experiments by Mr. Grove, showing that an electrical discharge does not take place through a perfect vacuum.

all the atoms of a body, however great may be the mass; and thus the number of atoms put in motion by it must be incalculably more numerous than those put in motion by electricity Further, the atoms of the atmosphere contiguous to a heated body are constantly moving from it, their place being occupied by others; so that whilst the atmosphere maintains the atoms of an electrified body in a state of vibration, it has the contrary effect on the atoms of the surface of a heated body.

122. In the action of a freely polarized body on one in its natural state (Section 112), whilst the result is the accumulation of free negative polarity at one end, and free positive polarity at the other end of R, the manner in which this is effected is tantamount to a momentary current of free positive polarity from the end further from, to the end nearer to, S, and to a current of free negative polarity in the opposite direction; for when *b* and *h* approach each other, the result is the production of free positive polarity in the hemisphere of *h* nearer S, and of free negative polarity in the hemisphere of *b* further from S. Again, when *b* and *g* approach each other, the free negative polarity on *b* is neutralized, whilst free positive polarity is produced on the hemisphere nearer S, the free positive polarity on *g* being at the same time neutralized, whilst free negative polarity is produced on the hemisphere further from S. The result is thus the same as if free negative polarity had been transferred from *h* to *b*, and from *b* to *g*, whilst free positive polarity was transferred from *g* to *b*, and from *b* to *h*.

123. If, then, P be a body polarized with free positive polarity, the action on R must continue unchanged in kind; the only difference being, that by the mutual action of S and P the production of polarity on R must be greatly augmented.

If, then, the free negative and positive polarities at the opposite ends of R were neutralized as soon as formed, instead of a momentary current there would be produced a succession of currents, and this would be analogous to the action which produces a galvanic current. Let D, C, B, A, A′, B′, C′, D′,

represent two rows of elemental atoms of different descriptions of matter. Let A and A′ combine; as they approach each other, they must be oppositely polarized (Section 51). This polarity must increase to a maximum, and, if they still continue to approach each other, must again decrease. Further, their respective distances from B and B′ must constantly increase as they approach each other. Hence, as A and A′ combine, their respective polar actions on B and B′ must rise to a maximum and again decrease to a minimum; and, as the distance between the atoms is a constantly increasing one, the action must be altogether inductive, and A must act on B, C, D, and A′ on B′, C′, D′, precisely as S acted on R (Section 112). Let D and D′ be joined by a conductor; then, if the polarity induced by A on the nearer hemisphere of B be positive, there must result a momentary current of free positive polarity along the conductor from B′ to B, and a momentary current of free negative polarity in the opposite direction. But if the polarity induced by A on B be positive, that induced by A′ on the nearer hemisphere of B′ must be negative, and hence must result momentary currents of free polarity, coinciding in direction with those produced by the action of A on B. Free positive polarity must thus be produced on the hemisphere of B nearer A, and free negative polarity on the hemisphere of B′ nearer A′; but, when atoms A and A′ have combined, atoms B and B′ will combine; as they approach, the free polarity on their inner hemispheres must be neutralized; further, they must act on the atoms C and C′ precisely as they were themselves acted on by the atoms A and A′. Whilst chemical combination continues, there must thus be produced a constant succession of momentary currents of free polarity along the conductor. It is evident that the force of each of these currents must rise to a maximum, and again decrease to a minimum; hence the successive currents must form a series of polar undulations flowing along the conductor, the whole action thus coinciding with the action on R of S and P when oppositely polarized, sup-

posing the free polarity on either end of R neutralized as soon as formed. But, practically, when two substances are combining, it is not from a single row of atoms that the action proceeds; and as, of the atoms forming the surfaces, some must just be separating from their masses, whilst others are again coming to rest,—that is, as there must, at the same instant, be atoms in all stages of combination, and as they must each be propagating a polar undulation along the conductor,—it follows, that at each point of the conductor there must be undulations in all the different stages of increase and decrease, and consequently the polar action of the conduetor on bodies external to it must be that of a constant, and not that of an undulating polarity; that is, if the cause of magnetism be a constant polarity, the inductive action of a wire along which a galvanic current is flowing must be magnetical, and not electrical.

124. When, however, an electrified body acts upon another body, as when a succession of electric sparks is passed along a conductor, the result must evidently be a succession of polar waves. May we not have in this an explanation of the action of a conductor, in such circumstances, on a magnetic needle? —the undulations from different points of the wire interfering at one distance, and producing a constant polar force, and consequently a magnetic action; at another distance, coinciding, and producing an electrical action.

125. When the result of the chemical action of two substances is to produce a galvanic current, the heat which would otherwise result cannot be produced; for, whilst A is increasing the polarity of one hemisphere of B, A′ must be acting on the opposite hemisphere through the conductor, thus increasing the attraction between B and C, and to a corresponding extent neutralizing the vibratory action described in Section 58.

126. When the points D and D′ are connected, the current flowing along the conductor must, at the commencement of the action, increase in strength till it reaches a maximum. Its action, during this time, must be that of a polar undula-

tion, for the difference between the strength of the polarity of the successive curves must rise to a maximum and decrease to a minimum. Hence, supposing a wire laid beside, but not in connexion with the conductor, the current flowing along the conductor would, until its action became constant, act by induction on the atoms of the wire, producing polar currents therein. Further, if the connexion between D and D′ was broken, momentary currents in a reverse direction would be produced in the wire; because, when the connexion between D and D′ was broken, the atoms of the conductor would return to their ordinary state, and this must be tantamount to a momentary reverse current, which must rise to a maximum and decrease to a minimum.

127. If D and D′ were the poles of a magnet alternately approaching to and receding from the ends of the conductor, the polar action of the magnet (supposing it to be a source of constant polarity) would increase as its poles approached the conductor, then become constant, and again decrease as they receded. The action of the magnet, as it approached the conductor, would thus coincide with the inductive action of a galvanic current when the poles are connected. When the action of the magnet became constant, it would coincide with that of the constant current; and when it receded from the conductor, the action would be the same as that of a current when contact was broken.

128. From the above reasoning it follows that it is not absolutely necessary for the production of a galvanic current that the points D and D′ be joined by a conductor; for, if there were no such conductor, whatever free polarity was produced on B and B′ during the combination of atoms A and A′ would still be neutralized when the atoms combined; if, then, by any means the free polarities induced on D and D′ were neutralized as they formed, all the conditions necessary for the production of a galvanic current would exist.

129. When a conductor charged with electricity is placed in connexion with the earth, the conducting surface over

which it is diffused is so large that the conductor is, practically speaking, perfectly discharged. May not this be the true reason why the earth apparently completes a galvanic current? According to this view of the subject, when the end of a wire from one pole of a battery is placed in connexion with the earth in Ireland, and the end of a wire from the other pole is buried in the earth at Newfoundland, the ends of the two wires are simply placed in connexion with conducting surfaces so large that they are kept, practically speaking, perfectly neutral; and consequently the distance between the points at which they are connected with the earth is perfectly immaterial, supposing the wires perfect conductors. But if the earth conduct the current in the same manner that the conductor joining the points D and D′ does, then every atom of matter in the line joining the points at which the wires are connected with the earth must have its polarity constantly changed by the passing currents: a conclusion by no means probable, considering the imperfect conducting powers of the substances of which the earth is principally composed, and the perfect manner in which even a thin film of a non-conducting substance intercepts a galvanic current.

130. The atoms of all bodies on the earth being in a state of vibration from the effects of heat, when an undulating polarity acts on a body, its action must coincide with that of heat, increasing the vibrations of the atoms of the body, and thus, to some extent, producing conduction. But when a constant polarity acts on such a body, its action must be opposed to that of heat, its tendency being evidently to destroy the vibrations of the atoms of the body; hence conduction can never arise from the action of a constant polarity. Again, when from the action of a constant polarity the opposite ends of a body are oppositely polarized to each other, the positive poles of the atoms of such body must be all pointing in one direction, and the negative poles in the other; and this can never happen so long as the atoms of a body not freely polarized vibrate to and from each other directly; for, in this case,

the atoms must be polarized alternately similarly and oppositely to each other.

When, therefore, attraction takes place between two bodies, one of which is a source of constant polarity, this latter must have sufficient strength so far to counteract the effects of heat as to maintain in an oppositely polarized state such a number of atoms that their action becomes the preponderating polar action of the body. This opposite polarization of its constituent atoms is, as is well known, one of the chief characteristics of a magnet. If, then, a magnet be a polarized body whose polarity is a uniform force, it is only on other magnets, or bodies capable of magnetization, that it can exercise an attractive action. It could not, for example, attract an electrified body, for, its action being wholly inductive, it could not increase the free polarities on it; but, according to the latter part of Section 43, the attractive force between two polarized bodies depends on the increase of polarity produced by their mutual action.

131. The atoms of a non-magnetic body being, from the action of heat, alternately similarly and oppositely polarized to each other, the opposite ends of such a body may be considered as alternately similarly and oppositely polarized. In the latter case, for reasons given in the preceding section, no attraction between the body and a magnet could result; but in the former case, a repulsive action should result (Section 43); and experience tells us that such an action (to which Dr. Faraday has given the name of diamagnetic) does take place*.

As the polarity of bodies at ordinary temperatures must be very small, this repulsion must be relative, and not absolute; that is, the action can be only a weakening of the ordinary attraction, which appears as repulsion, solely from the state of equilibrium which existed before the action commenced.

* It is not, however, absolutely necessary that the opposite ends of the diamagnetic body become similarly polarized; as, in the case of non-conducting bodies, a diamagnetic body may be considered as a neutral mass having a thin film of similarly polarized matter on its surface.

This agrees with the fact that diamagnetic action varies with the surrounding medium: the weaker polarity may be simply displaced by a stronger, in the same manner that a stone displaces the liquid through which it falls.

132. Two magnets may approach with such velocity that the atoms of that part of their surfaces which come in contact may become similarly polarized, approaching each other so closely as to produce conduction; but, so long as magnetic action continues, the two bodies contain within themselves the power of again oppositely polarizing the two surfaces, when, from mutual repulsion, they separate; and thus, when the two bodies come to rest, their adjacent surfaces must be oppositely polarized, as in the case of unequal atoms, Section 53.

133. It is evident that an absolutely constant polarity can only emanate from a body whose atoms are in a state of absolute rest; and this can hardly be the case with any substance on the earth. But, if the vibration of the atoms, at least of a sufficient number of them, be all in parallel planes, and in the direction at each point of a tangent to the surface, the polarity emanating from these atoms may be, practically speaking, constant. For when A (Section 71) vibrates in a direction transverse to A B, the minimum distance between A and B continues A B; hence their mutual action must be inductive, but the polarity would not be of uniform strength. But, although in the case of an electrified body, as is evident from the reasoning in Section 107, it is, strictly speaking, the surface which is electrified, and therefore no interference of the polar undulations can take place, yet, magnetism depending on the atoms being oppositely polarized to each other, it is improbable that this action can be altogether confined to the surface, though it may penetrate but a small distance into the interior; hence, in the same manner that the absorption of light has been explained (Section 67), the polar undulations emanating from one atom may interfere with and destroy those emanating from another, and the result be a constant polarity emanating from the body. Further, as the action of

the atoms on each other is still inductive, when a constant polarity acts on them, it must increase this inductive action, thus acting on them in the same manner that it would have done had the atoms been absolutely at rest.

134. As when two unequal atoms come to rest they are oppositely polarized, it follows that, but for the action of heat, two such atoms would be always magnetical. But, even supposing the action of heat, at ordinary temperatures, not sufficient to destroy the magnetic character of a compound atom, it does not follow that a mass of such atoms would be a magnet; for it might happen that whilst the positive pole of one of its constituent atoms pointed in one direction, the positive pole of another might point in the opposite direction; but if any external force could cause all the positive poles to point in one way, then, whilst under its influence, such a body would be a magnet, and might continue to be so after the external force ceased to act. This harmonizes well with the magnetic character of steel. Produced by the combination of iron and charcoal at a very high temperature, its atoms must be vibrating in all directions; and therefore, when it has cooled, unless acted on by some external force, it is improbable that the similar poles of the atoms can all point in one direction; but, when under the influence of such a force the poles of the atoms are so arranged, the effect is permanent.

135. When, then, we analyse the actions which produce electricity, we find that an undulating polarity is the operating cause, and that, whenever this polar action becomes uniform, all electrical effects cease, and magnetical effects are produced, when the substances acted on are capable of magnetization.

CHAPTER VI.

CONCLUSION.

REVIEWING the reasoning in the second and third chapters, there appear to be five propositions, from which, regarded as hypotheses, the different results might all be deduced.

1. When an atom and a mass act on each other, the outward force of the mass, plus the inward force of the atom, impinging on its inner hemisphere, are together equal to the ordinary force of that hemisphere.

2. When an atom is in motion, the centre toward which the inward curves are flowing participates in that motion.

3. The distance between two successive curves increases as the square of the distance increases.

4. When two outward curves, oppositely but unequally polarized, act on each other (supposing polarity to consist in that change of form described in Section 23), the weaker pole is increased, and the stronger decreased: if the curves are similarly polarized, both poles are decreased.

5. The elemental atoms of chemistry are not simple centres of force, but groups of such centres.

The last proposition is altogether hypothetical; I have endeavoured to prove that the others are direct results of the theory that an atom of matter is a centre to and from which force is constantly flowing.

From the first proposition flow the phænomena of gravitation; from the second, the stability of the system when an atom is in motion—uniform motion, and the transverse action of the curves; the third gives as its result the uniform velocity of the force at all distances from the centre; the fourth, combined with the first, gives rise to the various phæ-

nomena of polarity; whilst from the last, combined with one or more of the others, have been deduced many of the various phænomena of light, heat, electricity, and magnetism.

But it is not only in the number of the results obtained that the strength of the argument consists; we have other and very strong arguments in the fact, that, when we have arrived at an explanation of one particular phænomenon, that explanation of itself often necessitates a long train of consequences explanatory of other phænomena, many of them having no apparent connexion with the first, and in the manner in which the more direct results react on each other, producing fresh series of consequences. Thus the evidence of the existence of the transverse action of the curves of force lies in the steps of that demonstration by which we arrived at the conclusion that when an atom is in motion the inward curves participate in that motion. Now a belief in a transverse action of the rays of light has, despite its seeming paradox, forced itself upon the creed of men of science by the beautiful manner in which many of the phænomena of the polarization of light are thereby explained; that such an action should be a consequence of a theory must therefore of itself be a strong argument in its favour; but when we find, as in this case, the same reasoning leading to two results apparently altogether independent of each other, the undesigned coincidence gives to the argument a force and a value which it otherwise would not possess.

Apparently, this transverse action must decrease, not as the square, but as the fourth power of the distance from its source; for it must decrease as the distance between the rays of maximum force, and, apparently, also as the strength of the force emanating from a mass decreases. But that this latter cause does not affect the strength of the transverse action is a consequence of the conclusion forming the third proposition; and this result was arrived at, not in reasoning

on the transverse action, but in attempting to discover how the force emanating from a mass could decrease whilst its velocity remained constant. Further, it is because this law of decrease has this peculiar origin, that it is not invariably applicable, and that the rate of decrease, in the case of reflected or refracted light, depends, *cæteris paribus*, on the divergency of the rays in the incident beam.

Again, supposing the transverse action continuous in one direction, and combining with this the effect of the changing direction in which an atom in motion attracts another, we arrive at the conclusion that, within certain limits, the rotatory velocity thus produced must increase as the square root of the distance; and, applying this apparently paradoxical result to the case of the rotation of the planets, we obtain a close approximation to their observed periods. Further, this direct result of an atom's motion (which I have called its tangential action), thus forced upon our notice, enables us, from the peculiar laws which it obeys, to demonstrate how, practically speaking, the planets revolve in their orbits, as if they moved in a perfect vacuum, although they are in reality moving through a resisting medium; whilst comets, being transparent bodies, must be acted on by accelerating and retarding forces unequal in their action, and therefore producing continual, though possibly periodical, changes in their orbits.

The proposition that an outward polarized curve has its polarity increased as it approaches an oppositely polarized atom, and decreased as it approaches one similarly polarized, rather suggests a decrease of attraction in the first case, and an increase in the second; and it is only when combined with the first proposition, that the coincidence between fact and theory becomes apparent. If, however, the result had not been thus indirectly obtained, we could not have explained how two atoms come to rest while still at some distance from each other; nor how a polarized atom, although it induces an

opposite polarity on another atom when at a great distance from it, induces a similar polarity when the distance is short; nor how masses whose constituent atoms are similarly polarized always repel each other. But these results would have had a very limited practical application, except for the idea that the elemental atoms of chemistry are not simple, but compound; an idea, arrived at solely as a means of obviating the objection that there must be a connexion between the chemical and gravitating forces. When, however, the results of polarity are combined with this idea, we are in possession of an explanation of the repellent action of heat—of latent heat—of electricity, magnetism, diamagnetism, and the action of electric currents.

Thus, then, whenever the action of one of the more direct results would lead to a law not in accordance with observation, we find it becoming involved with some other result of the theory, and the required law arising from their combined action. Have we not, then, in such coincidences, a strong proof of the truth of these views? Nay, would it not be an objection to their truth if the coincidences with observation arose always from the separate instead of the combined action of the direct results of the theory?—for it seems impossible that different actions, springing contemporaneously from the same source, should not modify each other. And when one of these more direct results is completely changed in its action when combined with others, and thus explains phænomena having no apparent connexion, and obeying altogether different laws, have we not an argument of a very strong and peculiar character, similar in its nature to that proof of its truth which a theory receives when future discoveries are found to obey its laws, or rather when a study of its action leads to future discoveries?

But even the fact that many of the results obtained arise from the combined action of the more direct results of the theory, gives to our position a strength which it otherwise

would not possess; for, as in one of those great triumphs of engineering skill, those railway bridges which span the broad valleys and rivers of the land, the parts are all so interwoven with each other, that each strengthens and is strengthened by the rest, so by their combined action do the various results arising from separate and independent trains of reasoning corroborate and strengthen each other.

Nor is the general conclusion arrived at, that all the various phænomena of the physical sciences have one common source —a result hitherto unanticipated; for, although the first discovered facts in the different branches of natural philosophy presented points of contrast so strong, and of resemblance so vague and indistinct, that the idea of a common origin could scarcely arise; yet, as observations multiplied, the points of resemblance increased rapidly in number and strength, until now in our day, owing no doubt to the discovery of the chemical action of galvanism, and to that long chain of experimental reasoning in electricity and magnetism in which the labours of Dr. Faraday occupy so pre-eminent a position, the idea has become familiar to the mind that all the six great branches of natural philosophy spring from a common origin, —that they are all but different parts of one great river. In the preceding chapters I have but endeavoured to show that this common origin may be found in the movements of the particles of an elastic medium to and from the different atoms of matter as centres, that such an action is sufficiently Protean in its results, and that the circumstances which modify it so as to cause it to act with such different effects are precisely those in which the different phænomena occur. Doubtless in a theory which, at its first enunciation, has had to be applied to so many and such diverse matters, it cannot but be that the reasoning on many points must be vague, and many objections overlooked; yet it appears to me that the series of coincidences between observation and theory is too long and too complicated, that it exists under too many dif-

ferent conditions and circumstances, to render it possible that my journey has all along been through Dreamland, and that the agreements with observation which have been noted are but those casual crossings of the paths of fact and fancy which vivify and give a semblance of reality to the vision of the dreamer.

NOTE TO SECTION 67.

This projectile force does not decrease precisely as the square of the distance, although the approximation to that law is too close to affect the conclusion in the text. If S (Figure 1) represent a hollow sphere rotating on an axis $c\,d$, its whole tangential action may be considered as emanating from its equator, because the surface may be divided into a series of parallel rings, whose planes are perpendicular to C D, and in any one ring every atom must act with the same tangential force on R, and the total action be therefore equal to the tangential force of the atom in the equator multiplied by the circumference of the ring. If, then, C c D d represent the equator of a hollow sphere rotating in the plane of the paper, the whole tangential action of the sphere may be considered as emanating therefrom, and must be nothing at C, c, D and d, and be at a maximum midway between these points, increasing as sin. cos. Hence tangential force acting on

$$\mathrm{R}=\frac{1}{(r-\cos\theta)^2+\sin^2\theta}-\frac{1}{(r+\cos\theta)^2+\sin^2\theta}=\frac{2r}{r^4+1}$$

(θ being equal to 45°); multiplying by $\frac{1}{r}$ and dividing by $\frac{1}{r^2}$, as explained in Section 96, there results $\dfrac{2}{r^2+\frac{1}{r^2}}=$ projectile force. The sum of the gravitating forces is, however, as $\dfrac{2\left(1+\frac{1}{r^2}\right)}{r^2+1+\frac{1}{r^2}}$ * (θ being in this case $=60°$).

---

* This expression, to be strictly accurate, must be multiplied by a variable quantity, $\frac{1}{r^2}$ being the true measure of the gravitating force. This correction is caused by the different inclinations of the lines joining R and the various parts of the spherical surface. This variable quantity must therefore equally modify the expression for the projectile force, and thus leave the ratio of the two forces as above stated.

Dividing the latter of these two expressions by the former, there results $1+\frac{1}{r^6+r^4+r^2}$. Hence, the mean velocity of a planet being accurately known, its distance, as calculated by the first expression, must approximate too closely to that deduced from the latter for observation to detect which is in error.

It, however, occurred to me, whilst these Sections were passing through the press, that such a law of decrease of the projectile force must materially modify the reasoning in Sections 99 and 100, on the eccentricity of the orbits, for it is the accumulated effects of long continued action that must in this case be considered. The greater the distance, the more closely does the rate of decrease of the projectile force approximate to that of gravity; between any two points, the former must therefore decrease more slowly than the latter, and must therefore be considered as retarding at perihelion and accelerating at aphelion; that is, as decreasing the eccentricity of the orbit. Again, referring to Section 99, the effect of the transverse force is to increase the eccentricity of the orbit. These two actions, therefore, oppose each other; both increase with the eccentricity, but the former increases in a higher ratio than the latter. Ultimately, therefore, the two actions must neutralize each other, and the orbit of a body revolving in the plane of the sun's equator thus reach a state of equilibrium, so far as these forces are concerned.

THE END.

Printed by Taylor and Francis, Red Lion Court, Fleet Street.

London, December 1858.

CATALOGUE OF BOOKS

PUBLISHED BY MR. VAN VOORST.

ZOOLOGY.

MAMMALIA.

History of British Quadrupeds, including the Cetacea. By THOMAS BELL, F.R.S., P.L.S., Professor of Zoology in King's College, London. Illustrated by nearly 200 Engravings, comprising portraits of the animals, and vignette tail-pieces. 8vo. New Edition in preparation.

Natural History of the Sperm Whale, and a Sketch of a South Sea Whaling Voyage. By THOMAS BEALE. Post 8vo, 12*s.* cloth.

BIRDS.

History of British Birds. By WILLIAM YARRELL, V.P.L.S., F.Z.S., &c. This work contains a history and a picture portrait, engraved expressly for the work, of each species of the Birds found in Britain. Three volumes, containing 550 Illustrations. Third Edition, demy 8vo, £4 14*s.* 6*d.*

Coloured Illustrations of the Eggs of British Birds, with Descriptions of their Nests and Nidification. By WILLIAM C. HEWITSON. Third Edition, 2 vols. 8vo, £4 14*s.* 6*d.* The figures and descriptions of the Eggs in this edition are from different specimens to those figured in the previous editions.

Systematic Catalogue of the Eggs of British Birds, arranged with a View to supersede the use of Labels for Eggs. By the Rev. S. C. MALAN, M.A., M.A.S. On writing-paper. 8vo, 8*s.* 6*d.*

Ornithological Rambles in Sussex. By A. E. KNOX, M.A., F.L.S. Third Edition. Post 8vo, with Four Illustrations by Wolf, 7*s.* 6*d.*

Falconry in the Valley of the Indus. By R. F. BURTON, Author of 'Goa and the Blue Mountains,' &c. Post 8vo, with Four Illustrations, 6*s.*

Monograph of the Birds forming the Tanagrine Genus CALLISTE; illustrated by Coloured Plates of all the known species. By P. L. SCLATER, M.A., Fellow of Corpus Christi College, Oxford, F.Z.S., &c. 8vo, £2 2*s.*

Birds of Jamaica. By P. H. GOSSE, F.R.S., Author of the 'Canadian Naturalist,' &c. Post 8vo, 10*s*.

The Dodo and its Kindred; or the History, Affinities and Osteology of the Dodo, Solitaire, and other Extinct Birds of the Islands Mauritius, Rodriguez, and Bourbon. By H. E. STRICKLAND, M.A., F.G.S., F.R.G.S., and R. G. MELVILLE, M.D. Edin., M.R.C.S. Royal 4to, with 18 Plates and other Illustrations, £1 1*s*.

Geographical and Comparative List of the Birds of Europe and North America. By CHARLES LUCIEN BONAPARTE, Prince of Musignano. 8vo, 5*s*.

Ornithological Synonyms. By the late HUGH EDWIN STRICKLAND, M.A., F.R.S., &c. Edited by Mrs. HUGH EDWIN STRICKLAND and SIR WILLIAM JARDINE, Bart., F.R.S.E., &c. 8vo, Vol. I. containing the Order Accipitres, 12*s*. 6*d*.

REPTILES.

History of British Reptiles. By THOMAS BELL, F.R.S., President of the Linnean Society, V.P.Z.S., &c., Professor of Zoology in King's College, London. Second Edition, with 50 Illustrations, 12*s*.

FISHES.

Production and Management of Fish in Fresh Waters, by Artificial Spawning, Breeding, and Rearing. By GOTTLIEB BOCCIUS. 8vo, 5*s*.

History of British Fishes. By WILLIAM YARRELL, V.P.L.S., F.Z.S., &c. Third Edition. Edited by SIR JOHN RICHARDSON, M.D. Two vols. demy 8vo, illustrated by more than 500 Engravings. Nearly ready.

Yarrell.—Growth of the Salmon in Fresh Water. With Six Coloured Illustrations of the Fish of the natural size, exhibiting its structure and exact appearance at various stages during the first two years. 12*s*. sewed.

Heraldry of Fish. By THOMAS MOULE. Nearly six hundred families are noticed in this work, and besides the several descriptions of fish, fishing-nets, and boats, are included also mermaids, tritons, and shell-fish. Nearly seventy ancient seals are described, and upwards of twenty subjects in stained glass. The engravings, two hundred and five in number, are from stained glass, tombs, sculpture and carving, medals and coins, rolls of arms, and pedigrees. 8vo, 21*s*.; a few on large paper (royal 8vo) for colouring, £2 2*s*.

Fly-Fishing in Salt and Fresh Water. With Six Coloured Plates, representing Artificial Flies, &c. 8vo, 7*s.* 6*d.*

An Angler's Rambles. By EDWARD JESSE, F.L.S., Author of 'Gleanings in Natural History.' Contents:—Thames Fishing—Trolling in Staffordshire—Perch Fishing Club—Two Days' Fly-fishing on the Test — Luckford Fishing Club — Grayling Fishing—A Visit to Oxford—The Country Clergyman. Post 8vo, 10*s.* 6*d.*

INVERTEBRATA.

Introduction to Conchology; or, Elements of the Natural History of Molluscous Animals. By GEORGE JOHNSTON, M.D., LL.D., Fellow of the Royal College of Surgeons of Edinburgh, author of 'A History of the British Zoophytes.' 8vo, 102 Illustrations, 21*s.*

"The book is a convincing proof that there is no subject, however dry and unpromising, that may not be made interesting by a man of taste, genius, and learning. Dr. Johnston's object has been to present the conchologist with a view of the economical, physiological, and systematical relations of molluscous animals to each other and to other created beings; and this he has done in a style so elegant and captivating, and with such a happy facility of illustrating his theories by learned references and curious anecdotes, that it is not easy to decide whether his work is most valuable as a scientific, or interesting as a literary composition."—*Morning Post.*

History of British Mollusca and their Shells. By Professor ED. FORBES, F.R.S., &c. and SYLVANUS HANLEY, B.A., F.L.S. Illustrated by a figure of each known Animal and of all the Shells, engraved on 203 copper-plates. 4 vols. 8vo, £6 10*s.*; royal 8vo, with the plates coloured, £13.

Synopsis of the Mollusca of Great Britain. Arranged according to their Natural Affinities and Anatomical Structure. By W. A. LEACH, M.D., F.R.S., &c. &c. Post 8vo, with 13 Plates, 14*s.*

History of the British Marine Testaceous Mollusca, described in their Natural Order, on the Basis of the Organization of the Animals, with References and Notes on every British species. By WILLIAM CLARK. 8vo, 15*s.*

Thesaurus Conchyliorum. By G. B. SOWERBY. Imp. 8vo, Eighteen Parts, £1 5*s.* each.

Malacologia Monensis. A Catalogue of the Mollusca inhabiting the Isle of Man and the neighbouring Sea. By EDWARD FORBES. Post 8vo, 3*s.*, Edinburgh, 1838.

History of British Star-fishes, and other Animals of the Class Echinodermata. By EDWARD FORBES, M.W.S., Professor of Botany in King's College, London. 8vo, with more than 120 Illustrations, 15*s.*, or royal 8vo, 30*s.*

Genera of Recent Mollusca; arranged according to their Organization. By HENRY AND ARTHUR ADAMS. This work contains a description and a figure engraved on steel of each genus, and an enumeration of the species. 3 vols. 8vo, £4 10*s.*; or royal 8vo, with the plates coloured, £9.

Elements of Entomology: an Outline of the Natural History and Classification of British Insects. By WILLIAM S. DALLAS, F.L.S. Post 8vo, 8*s.* 6*d.*

The Entomologist's Annual for 1855 to 1858. Duodecimo, boards, 2*s.* 6*d.* each.

History of British Stalk-eyed Crustacea (Lobsters, Crabs, Prawns, Shrimps, &c.). By THOMAS BELL, President of the Linnean Society, F.G.S., F.Z.S., Professor of Zoology in King's College, London. The volume is illustrated by 174 Engravings of Species and tail-pieces. 8vo, £1 5*s.*; royal 8vo, £2 10*s.*

History of the British Zoophytes. By GEORGE JOHNSTON, M.D., LL.D. Second Edition, in 2 vols. 8vo, with an illustration of every species. £2 2*s.*; or on large paper, royal 8vo, £4 4*s.*

Manual of the Sea-Anemones commonly found on the English Coast. By the Rev. GEORGE TUGWELL, Oriel College, Oxford. Post 8vo, with Coloured Illustrations, 7*s.* 6*d.*

Natural History of Animals. By Professor T. RYMER JONES. Vol. II. Insects, &c., with 104 Illustrations, post 8vo, 12*s.*

Familiar Introduction to the History of Insects; being a Second and greatly Improved Edition of the Grammar of Entomology. By EDWARD NEWMAN, F.L.S., Z.S., &c. With nearly 100 Illustrations, 8vo, price 12*s.*

The World of Insects; a Guide to its Wonders. By J. W. DOUGLAS, Secretary to the Entomological Society of London. This work contains rambling observations on the more interesting members of the Insect World to be found in the House, the Garden, the Orchard, the Fields, the Hedges, on the Fences, the Heaths and Commons, the Downs, in the Woods, the Waters, or on the Sea Shore, or on Mountains. 12mo, stiff-paper wrapper, 3*s.* 6*d.*

Siebold on True Parthenogenesis in the Honey-Bee and Silk-Worm Moth. Translated from the German by W. S. DALLAS, F.L.S. 8vo, 5*s.*

Practical Hints respecting Moths and Butterflies, with Notices of their Localities; forming a Calendar of Entomological Operations throughout the Year, in pursuit of Lepidoptera. By RICHARD SHIELD. 12mo, stiff-paper wrapper, 3*s.*

Hewitson's Exotic Butterflies. Vol. I., containing 398 Coloured Figures of new or rare species, Five Guineas.

"In this work there is a truthfulness of outline, an exquisite delicacy of pencilling, a brilliancy and transparency of colouring, that has rarely been equalled and probably never surpassed."—*The President in his Address to the Entomological Society*, 1856.

Of Vol. II., Eight Parts (21 to 28 of the entire work) are at this time published, 5*s.* each.

Manual of British Butterflies and Moths. By H. T. STAINTON, Editor of 'The Entomologist's Annual.' 12mo. To be completed in 30 Numbers at 3*d.* each; 23 at this time published.

Natural History of the Tineina. By H. T. STAINTON, Coloured Plates. Vol. I. to III. 8vo, cloth, each 12*s.* 6*d.*

Entomologist's Companion (to the Tineina). By H. T. STAINTON. Second Edition, 12mo, 3*s.*

Geodephaga Britannica: a Monograph of the Carnivorous Ground-Beetles Indigenous to the British Isles. By J. F. DAWSON, LL.B. 8vo, with Three Coloured Plates, 12*s.*

Insecta Maderensia; being an Account of the Insects of the Islands of the Madeiran Group. By T. VERNON WOLLASTON, M.A., F.L.S. 4to, with Thirteen Coloured Plates of Beetles, £2 2*s.*

BOTANY.

Weeds and Wild Flowers. By LADY WILKINSON. Post 8vo, with Coloured Engravings and Woodcuts. 10*s.* 6*d.*

Manual of British Botany; containing the Flowering Plants and Ferns, arranged according to their Natural Orders. By C. C. BABINGTON, M.A., F.R.S., F.L.S., &c. 12mo, the Fourth Edition, with many additions and corrections, 10*s.* 6*d.*, cloth.

Elementary Course of Botany; Structural, Physiological, and Systematic. With a brief Outline of the Geographical and Geological Distribution of Plants. By ARTHUR HENFREY, F.R.S., L.S., &c., Professor of Botany in King's College, London, Examiner in Natural Science to the Royal Military Academy and to the Society of Arts. Illustrated by upwards of 500 Woodcuts. Post 8vo, 12*s.* 6*d.*

Also by Professor Henfrey.

Vegetation of Europe, its Conditions and Causes. Foolscap 8vo, 5*s.*

Principles of the Anatomy and Physiology of the Vegetable Cell. By HUGO VON MOHL. Translated, with the author's permission, by ARTHUR HENFREY, F.R.S., &c. 8vo, with an Illustrative Plate and numerous Woodcuts, 7*s.* 6*d.*

Rudiments of Botany. A Familiar Introduction to the Study of Plants. With Illustrative Woodcuts. Second Edition, foolscap 8vo, 3*s.* 6*d.*

A Set of Six Coloured Diagrams illustrative of the Rudiments of Botany; for Schools and Lectures. 15*s.*

History of British Forest-Trees. By PRIDEAUX JOHN SELBY, F.R.S.E., F.L.S., &c. Each species is illustrated by a portrait of some well-known or fine specimen, as a head-piece; the leaf, florification, seed-vessels, or other embellishments tending to make the volume ornamental or useful, are embodied in the text or inserted as tail-pieces. 8vo, with nearly 200 Illustrations, £1 8*s.*

Manual Flora of Madeira and the adjacent Islands of Porto Santo and the Dezertas. By R. T. LOWE, M.A. 12mo. Part I. Thalamifloræ, 3*s.* 6*d.*

Primitiæ et Novitiæ Faunæ et Floræ Maderæ et Portus Sancti. Two Memoirs on the Ferns, Flowering Plants, and Land Shells of Madeira and Porto Santo. By R. T. LOWE, M.A. 12mo, 6*s.* 6*d.*, boards (150 copies printed).

Growth of Plants in closely Glazed Cases. By N. B. WARD, F.R.S., F.L.S. Second Edition, Illustrated. Post 8vo, 6*s.*

The Sea-Weed Collector's Guide; containing plain Instructions for Collecting and Preserving; and a List of all the known Species and Localities in Great Britain. By J. COCKS, M.D. Foolscap 8vo, 2*s.* 6*d.*

Manual of the British Marine Algæ, containing Generic and Specific Descriptions of all the known British Species of Sea-Weeds, with Plates to illustrate all the Genera. By W. H. HARVEY, M.D., M.R.I.A., Keeper of the Herbarium of the University of Dublin, and Professor of Botany to the Royal Dublin Society. 8vo, £1 1*s.*; Coloured Copies, £1 11*s.* 6*d.*

Nereis Boreali-Americana; or, Contributions towards a History of the Marine Algæ of the Atlantic and Pacific Coasts of North America. By W. H. HARVEY, M.D., M.R.I.A., &c. Royal 4to, with 50 Coloured Plates, £3 3*s.*

Terra Lindisfarnensis. The Natural History of the Eastern Borders. By GEORGE JOHNSTON, M.D., &c., &c. This volume embraces the Topography and Botany; and gives the popular Names and Uses of the Plants, and the Customs and Beliefs which have been associated with them. The chapter on the Fossil Botany of the district is contributed by GEORGE TATE, F.G.S. Illustrated with a few Woodcuts and 15 Plates, 8vo, 10*s.* 6*d.*

History of British Ferns. By EDWARD NEWMAN. Comprising under each Species, Figures, detailed Descriptions, an ample List of Localities, and minute Instructions for Cultivating. 8vo, 18*s.*

Walks after Wild Flowers; or the Botany of the Bohereens. By RICHARD DOWDEN. Foolscap 8vo, 4*s.* 6*d.*

Synopsis of the British Diatomaceæ; with Remarks on their Structure, Functions, and Distribution; and Instructions for Collecting and Preserving Specimens. By the Rev. WILLIAM SMITH. The Plates by TUFFEN WEST. In 2 vols. royal 8vo; Vol. I. 21*s.*; Vol. II. 30*s.*

CHEMISTRY, MINERALOGY, GEOLOGY.

A Manual of Chemical Analysis (Qualitative). By A. B. NORTHCOTE, F.C.S., and ARTHUR H. CHURCH, F.C.S. Post 8vo, 10*s.* 6*d.*

Handbook of Chemical Manipulation. By C. GREVILLE WILLIAMS, Principal Assistant in the Laboratory of the University of Edinburgh. Post 8vo, with very numerous Woodcut Illustrations, 15*s.*

Elementary Course of Geology, Mineralogy, and Physical Geography. By DAVID T. ANSTED, M.A., F.R.S., F.G.S., &c., Consulting Mining Engineer, Honorary Fellow of King's College, London, Lecturer on Mineralogy and Geology at the H.E.I.C. Mil. Sem. at Addiscombe, late Fellow of Jesus College, Cambridge. A Second Edition, post 8vo, with many Illustrations, 12*s.*

The Ancient World. By Professor ANSTED. Second Edition, post 8vo, 10*s.* 6*d.*, with 149 Illustrations.

"The work may be described as an outline of the history of vegetable and animal life upon the globe, from the early age when there were only sea-weeds and marine invertebrates as yet in existence, down to the era when the mammals received among them the king of species, Man. By his intimate acquaintance with the subject, and power of arrangement and description, Professor Ansted succeeds in producing a narration, which tells in its entire range like a romance."—*Manchester Examiner.*

Gold-Seeker's Manual. By Professor ANSTED. Foolscap 8vo, 3*s.* 6*d.*

Geologist's Text-Book. Chiefly intended as a Book of Reference for the Geological Student. By Professor ANSTED. Foolscap 8vo, 3*s.* 6*d.*

The Ground beneath us; its Geological Phases and Changes. Three Lectures on the Geology of Clapham and the neighbourhood of London generally. By JOSEPH PRESTWICH, F.R.S., F.G.S. &c. 8vo, 3*s.* 6*d.* sewed.

Manual of the Mineralogy of Great Britain and Ireland. By ROBERT PHILIPS GREG, F.G.S., and WILLIAM G. LETTSOM. 8vo, with numerous Woodcuts, 15*s.*

History of British Fossil Mammals and Birds. By Professor OWEN. This volume is designed as a companion to that by Professor Bell on the (Recent Mammalia) 'British Quadrupeds and Cetacea.' 8vo, with 237 Illustrations, £1 11*s.* 6*d.*, or large paper (royal 8vo), £3 3*s.*

Description of the Skeleton of an Extinct Gigantic Sloth (Mylodon robustus). With Observations on the Osteology, Natural Affinities, and probable Habits of the Megatherioid Quadrupeds in general. By RICHARD OWEN, F.R.S., &c. 4to. £1 12*s.* 6*d.*

Geological Inquiry respecting the Water-bearing Strata of the Country around London, with reference especially to the Water Supply of the Metropolis, and including some Remarks on Springs. By JOSEPH PRESTWICH, Jun., F.G.S., &c. 8vo, with a Map and Woodcuts, 8*s.* 6*d.*

Memoirs of Hugh E. Strickland, M.A., Deputy Reader of Geology in the University of Oxford. By SIR WILLIAM JARDINE, Bart.; with a selection from his Printed and other Scientific Papers. One Vol. Royal 8vo, 36*s.*, Illustrated by Maps, Geological Sections, Plates and Woodcuts.

Omphalos. An Attempt to Untie the Geological Knot. By P. H. GOSSE, F.R.S. In this work the author aims to overthrow the received conclusions of geologists as to the remote antiquity of the earth, by the enunciation and illustration of a grand physical law, hitherto unrecognized, the law of Prochronism in organic creation. Post 8vo, pp. 376, with 56 Illustrations on wood, 10*s.* 6*d.*

WORKS ON GENERAL NATURAL HISTORY, &c.

The Aquarian Naturalist: a Manual for the Sea-side. By Professor T. RYMER JONES, F.R.S. Post 8vo, 544 pp., with 8 Coloured Plates, price 18*s.*

Humble Creatures: the Earthworm and the Common Housefly. In Eight Letters. By JAMES SAMUELSON, assisted by J. A. HICKS, M.D. Lond., F.L.S. With Microscopic Illustrations by the Authors. Post 8vo, price 3*s.* 6*d.*

The Micrographic Dictionary: a Guide to the Examination and Investigation of the Structure and Nature of Microscopic Objects. By Dr. GRIFFITH and Professor HENFREY. Illustrated by 41 Plates, each with numerous Figures, some coloured, and 816 Woodcuts, 777 pages, 8vo, £2 5s.

Observations in Natural History; with a Calendar of Periodic Phenomena. By the Rev. LEONARD JENYNS, M.A., F.L.S. Post 8vo, 10s. 6*d*.

Observations in Meteorology; relating to Temperature, the Winds, Atmospheric Pressure, the Aqueous Phenomena of the Atmosphere, Weather Changes, &c.; being chiefly the results of a Meteorological Journal kept for 19 years at Swaffham Bulbeck, in Cambridgeshire, and serving as a guide to the climate of that part of England. By the Rev. LEONARD JENYNS, M.A., F.L.S., &c., late Vicar of Swaffham Bulbeck. Post 8vo, 10s. 6*d*.

Practical Meteorology. By JOHN DREW, Ph.D., F.R.A.S., Corresponding Member of the Philosophical Institute of Bâle. Foolscap 8vo, with 10 Illustrative Plates, 5s.

Natural History of Animals: being the substance of Three Courses of Lectures delivered before the Royal Institution of Great Britain. By T. RYMER JONES, F.R.S., Professor of Zoology in King's College, London. Post 8vo. Vol. I. with 105 Illustrations; Vol. II. with 104 Illustrations, 12s. each.

General Outline of the Organization of the Animal Kingdom, and Manual of Comparative Anatomy. By T. RYMER JONES, F.R.S., Professor of Comparative Anatomy in King's College, London; late Fullerian Professor of Physiology to the Royal Institution of Great Britain, &c. &c. Second Edition, 8vo, 884 pages, 400 Woodcuts, £1 11*s*. 6*d*.

First Steps to Anatomy. By JAMES L. DRUMMOND, M.D., Professor of Anatomy and Physiology in the Belfast Royal Institution. With 12 Illustrative Plates. 12mo, 5s.

Great Artists and Great Anatomists: a Biographical and Philosophical Study. By R. KNOX, M.D., F.R.S.E. Post 8vo, 6s. 6*d*.

Anatomical Manipulation; or, The Methods of pursuing Practical Investigations in Comparative Anatomy and Physiology. Also an Introduction to the Use of the Microscope, &c. By ALFRED TULK, M.R.C.S., M.E.S.; and ARTHUR HENFREY, F.L.S., M.Micr.S. With Illustrative Diagrams. Foolscap 8vo, 9s.

Familiar Introduction to the Study of Polarized Light. By CHARLES WOODWARD, F.R.S. 8vo, Illustrated, 3s. Second Edition.

Illustrations of Instinct, deduced from the Habits of British Animals. By JONATHAN COUCH, F.L.S., Member of the Royal Geological Society, and of the Royal Institution of Cornwall, &c. Post 8vo, 8*s.* 6*d.*

The Powers of the Creator Displayed in the Creation; or, Observations on Life amidst the various forms of the Humbler Tribes of Animated Nature; with Practical Comments and Illustrations. By Sir JOHN GRAHAM DALYELL, Knt. and Bart. In 3 vols. 4to, containing numerous Plates of living subjects, finely coloured, £10 10s.

Rare and Remarkable Animals of Scotland, with Practical Observations on their Nature. By Sir JOHN GRAHAM DALYELL, Knt. and Bart. In 2 vols. 4to, containing 110 Coloured Plates, drawn from the living subjects, £6 6*s.*

On the Variation of Species, with especial reference to the Insecta; followed by an Inquiry into the Nature of Genera. By T. VERNON WOLLASTON, M.A., F.L.S. Post 8vo, 5*s.*

> "No compound of this earthly ball
> Is like another, all in all."—*Tennyson.*

Manual of Natural History for the Use of Travellers; being a Description of the Families of the Animal and Vegetable Kingdoms, with Remarks on the Practical Study of Geology and Meteorology. To which are appended Directions for Collecting and Preserving. By ARTHUR ADAMS, M.R.C.S.; W. BALFOUR BAIKIE, M.D.; and CHARLES BARRON, Curator of the Royal Naval Museum at Haslar. Post 8vo, 12s.

Letters of Rusticus on Natural History. Edited by EDWARD NEWMAN, F.L.S., F.Z.S., &c. 8vo, 8*s.* 6*d.*

Descriptive Ethnology. By ROBERT GORDON LATHAM, M.D., F.R.S., Fellow of King's College, Cambridge; Vice-President of the Ethnological Society of London; Corresponding Member of the Ethnological Society of New York. 2 vols. 8vo.

Other Works on Ethnology, by Dr. Latham.

Natural History of the Varieties of Man. 8vo, Illustrated, £1 1*s.*

Ethnology of Europe. Foolscap 8vo, 5*s.*

Ethnology of the British Islands. Foolscap 8vo, 5*s.*

Ethnology of the British Colonies and Dependencies. Foolscap 8vo, 5*s.*

Man and his Migrations. Foolscap 8vo, 5*s.*

The Sea-side Book: an Introduction to the Natural History of the British Coasts. By W. H. HARVEY, M.D., M.R.I.A., &c. With a Chapter on Fish and Fish Diet, by YARRELL. Foolscap 8vo, with 83 Woodcut Illustrations, 4th Edition, 5*s.*

Handbook to the Marine Aquarium: containing Practical Instructions for Constructing, Stocking, and Maintaining a Tank, and for Collecting Plants and Animals. By P. H. GOSSE, F.R.S. Foolscap 8vo, Second Edition, 2*s.* 6*d.*

Mr. Gosse's Manual of Marine Zoology of the British Isles. Parts I. and II., price 7*s.* 6*d.* each.

A Naturalist's Rambles on the Devonshire Coast. By P. H. GOSSE, F.R.S. With 28 Lithographic Plates, some coloured, post 8vo, One Guinea.

The Aquarium; an Unveiling of the Wonders of the Deep Sea. By P. H. GOSSE, F.R.S. Post 8vo, Illustrated, Second Ed. 17*s.*

The Canadian Naturalist. By P. H. GOSSE, F.R.S. With 44 Illustrations of the most remarkable Animal and Vegetable productions. Post 8vo, 12*s.*

Tenby; a Seaside Holiday. By P. H. GOSSE, F.R.S. Post 8vo, 400 pages, with 24 Coloured Plates, 21*s.*

The Isle of Man; its History, Physical, Ecclesiastical and Legendary. By J. G. CUMMING, M.A., F.G.S. Post 8vo, 12*s.* 6*d.*

Natural History of the County of Stafford; comprising its Geology, Zoology, Botany, and Meteorology: also its Antiquities, Topography, Manufactures, &c. By ROBERT GARNER, F.L.S. 8vo, with a Geological Map and other Illustrations, 21*s.*

The Natural History of Selborne. By the late Rev. GILBERT WHITE, M.A. A New Edition, with Notes by the Rev. LEONARD JENYNS, M.A., F.L.S., &c.; with 26 Illustrations, foolscap 8vo, 7*s.* 6*d.*

Travels in Lycia, Milyas, and the Cibyratis, in company with the late Rev. E. T. Daniell. By Lieut. SPRATT, R.N., and Professor EDWARD FORBES. Two vols. 8vo, with numerous Illustrations, including Views of the Scenery, Plans of Ancient Cities and Buildings, Plates of Coins and Inscriptions, Cuts of Rock Tombs, Fossils, and Geological Sections, and an original Map of Lycia. 36*s.*

Healthy Respiration. By STEPHEN H. WARD, M.D. Foolscap 8vo, 1*s.* 6*d.*

Tobacco and its Adulterations. By HENRY P. PRESCOTT, of the Inland Revenue Department. With upwards of 250 Illustrations drawn and engraved on Forty Steel Plates. 8vo, 12*s.* 6*d.*

A Life of Linnæus. By Miss BRIGHTWELL of Norwich. Foolscap 8vo, 3*s.* 6*d.*

Scenery, Science, and Art; being Extracts from the Notebook of a Geologist and Mining Engineer. By Professor D. T. ANSTED, M.A., F.R.S., &c. 8vo, with Woodcuts and Four Views in tinted lithography, 10*s.* 6*d.*

Evening Thoughts. By a PHYSICIAN. Post 8vo, Second Edition, 4*s.* 6*d.*

"We cannot help expressing a wish that these 'Evening Thoughts' may not be the only contributions to general literature that we may have from a mind so powerful, so cultivated, and so gentle as that of the Physician whose pages we now close."—*Guardian.*

Illustrations of Arts and Manufactures; being a Selection from a Series of Papers read before the Society for the Encouragement of Arts, Manufactures, and Commerce. By ARTHUR AIKIN, F.L.S., F.G.S., &c., late Secretary to that Institution. Foolscap 8vo, 8*s.*

The Poor Artist; or, Seven Eye-Sights and One Object. "SCIENCE IN FABLE." Foolscap 8vo, with a Frontispiece, 5*s.*

Sunday Book for the Young; or, Habits of Patriarchal Times in the East. With Woodcuts, 2*s.* 6*d.* By ANNE BULLAR.

Other Books for Young Persons, by Anne Bullar.

Domestic Scenes in Greenland and Iceland. With Woodcuts, 2*s.* Second Edition.

Every-Day Wonders; or, Facts in Physiology which all should know. With Woodcuts, 2*s.* 6*d.*

England before the Norman Conquest. 2*s.* 6*d.*

Elements of Practical Knowledge; or, The Young Inquirer Answered. Explaining in Question and Answer, and in familiar language, what most things daily used, seen, or talked of, are; what they are made of, where found, and to what uses applied. Including articles of food and aliment; miscellanies in common use; metals, gems, jewellery; and some account of the principal inventions and most interesting manufactures. Second Edition, 18mo, with Illustrations, 3*s.* cloth.

Notes on the Geology and Chemical Composition of the various Strata in the Isle of Wight. By CAPTAIN L. L. BOSCAWEN IBBETSON. With a Map in Relief, coloured Geologically, 8vo, 7*s.* 6*d.*

ARCHITECTURE AND THE FINE ARTS, &c.

Instrumenta Ecclesiastica; a Series of Working Designs, engraved on 72 Plates, for the Furniture, Fittings, and Decorations of Churches and their Precincts. Edited by the Ecclesiological, late Cambridge Camden Society. 4to, £1 11*s*. 6*d*.

The Second Series contains a Cemetery Chapel, with Sick-house and Gateway Tower—A Wooden Church—A Chapel School—Schools and School-houses—A Village Hospital—An Iron Church—And Designs for Funeral Fittings, for Timber Belfries, and for a Variety of Works in Metal, Wood, and Stone. Price also £1 11*s*. 6*d*.

Manual of Gothic Architecture. By F. A. PALEY, M.A. With a full Account of Monumental Brasses and Ecclesiastical Costume. Foolscap 8vo, with 70 Illustrations, 6*s*. 6*d*.

"To the student of the architecture of old English churches this beautiful little volume will prove a most acceptable manual. The two chapters on * * * form an epitome of the whole subject, so lucid, concise, and complete, that it may be regarded as a model of succinct and clear exposition. Both in description and analysis, Mr. Paley is remarkable for neatness and perspicuity; his style is terse and precise, yet withal easy and elegant. The examples, engraved by Thurston Thompson, are the perfection of wood engraving, as applied to architecture: exact in detail, picturesque in effect, and cut with equal firmness and delicacy."—*Spectator*.

Baptismal Fonts. A Series of 125 Engravings, examples of the different periods, accompanied with Descriptions; and with an Introductory Essay. By F. A. PALEY, M.A., Honorary Secretary of the Cambridge Camden Society. 8vo, One Guinea.

Treatise on the Rise and Progress of Decorated Window Tracery in England. By EDMUND SHARPE, M.A., Architect. 8vo, Illustrated with 97 Woodcuts and Six Engravings on steel, 10*s*. 6*d*. And a

Series of Illustrations of the Window Tracery of the Decorated Style of Ecclesiastical Architecture. Edited, with descriptions, by Mr. SHARPE. Sixty Engravings on steel, 8vo, 21*s*.

Heraldry of Fish. By THOMAS MOULE. The Engravings, 205 in number, are from Stained Glass, Tombs, Sculpture, and Carving, Medals and Coins, Rolls of Arms, and Pedigrees. 8vo, 21*s*. A few on large paper (royal 8vo) for colouring, £2 2*s*.

Shakspeare's Seven Ages of Man. Illustrated by WM. MULREADY, R.A.; J. CONSTABLE, R.A.; SIR DAVID WILKIE, R.A.; W. COLLINS, R.A.; A. E. CHALON, R.A.; A. COOPER, R.A.; SIR A. W. CALLCOTT, R.A.; EDWIN LANDSEER, R.A.; W. HILTON, R.A. Post 8vo, 6*s*. A few copies of the First Edition in 4to remain for sale.

Manual of Gothic Moldings. A Practical Treatise on their formations, gradual development, combinations, and varieties; with full directions for copying them, and for determining their dates. Illustrated by nearly 600 examples. By F. A. PALEY, M.A. Second Edition, 8vo, 7*s.* 6*d.*

"Mouldings are the scholarship of architecture. The present is a most learned work, and displays an amount of practical knowledge which those who know the difficulties of the subject alone can appreciate."—*Christian Remembrancer.*

Gray's Elegy in a Country Church-Yard. Each Stanza illustrated with an engraving on wood, from 33 original drawings. Elegantly printed, in post 8vo, 9*s.* cloth. (Small edition, 2*s.* 6*d.*)

A Polyglot Edition of this volume, with interpaged Translations in the Greek, Latin, German, Italian, and French languages. 12*s.*

Gray's Bard. With Illustrations by the Hon. Mrs. JOHN TALBOT. Post 8vo, 7*s.*

The Vicar of Wakefield. With 32 Illustrations by WILLIAM MULREADY, R.A.; engraved by JOHN THOMPSON. First reprint. Square 8vo, 10*s.* 6*d.*

"And there are some designs in the volume in which art may justly boast of having added something to even the exquisite fancy of Goldsmith." —*Examiner.*

The Farmer's Boy and other Rural Tales and Poems. By ROBERT BLOOMFIELD. Foolscap 8vo, 7*s.* 6*d.* A few copies on large paper, to correspond with the edition of 'The Vicar of Wakefield,' lately illustrated by WILLIAM MULREADY, R.A. With 13 Illustrations by Sidney Cooper, Horsley, Frederick Tayler, and Thomas Webster, A.R.A.

Watts's Divine and Moral Songs. With 30 Illustrations by C. W. COPE, A.R.A.; engraved by JOHN THOMPSON. Square 8vo, 7*s.* 6*d.*; copies bound in morocco, One Guinea.

The Economy of Human Life. In Twelve Books. By R. DODSLEY. With Twelve Plates, engraved on steel, from original designs, by Frank Howard, Harvey, Williams, &c. 18mo, gilt edges, 5*s.*

Bibliographical Catalogue of Privately Printed Books. By JOHN MARTIN, F.S.A. Second Edition, 8vo, 21*s.*

The Currency under the Act of 1844; together with Observations on Joint Stock Banks, and the Causes and Results of Commercial Convulsions. From the City Articles of "The Times." 8vo, 6*s.*

JOHN VAN VOORST, 1 PATERNOSTER ROW.

NATURAL HISTORY OF THE BRITISH ISLES.

This Series of Works is Illustrated by many Hundred Engravings; every Species has been Drawn and Engraved under the immediate inspection of the Authors; the best Artists have been employed, and no care or expense has been spared.

A few Copies have been printed on Larger Paper.

QUADRUPEDS, by Professor Bell. A New Edition preparing.

BIRDS, by Mr. Yarrell. Third Edition, 3 vols. £4 14*s.* 6*d.*

COLOURED ILLUSTRATIONS OF THE EGGS OF BIRDS, by Mr. Hewitson. Third Edition, 2 vols., £4 14*s.* 6*d.*

REPTILES, by Professor Bell. Second Edition, 12*s.*

FISHES, by Mr. Yarrell. Third Edition, edited by Sir John Richardson, 2 vols., nearly ready.

CRUSTACEA, by Professor Bell. 8vo, £1 5*s.*

STAR-FISHES, by Professor Edward Forbes. 15*s.*

ZOOPHYTES, by Dr. Johnston. Second Edition, 2 vols., £2 2*s.*

MOLLUSCOUS ANIMALS AND THEIR SHELLS, by Professor Edward Forbes and Mr. Hanley. 4 vols. 8vo, £6 10*s.* Royal 8vo, Coloured, £13.

FOREST TREES, by Mr. Selby. £1 8*s.*

FERNS, by Mr. Newman. Third Edition, 18*s.*

FOSSIL MAMMALS AND BIRDS, by Prof. Owen. £1 11*s.* 6*d.*

Students' Class-Books.

MANUAL OF CHEMICAL QUALITATIVE ANALYSIS. By A. B. Northcote, F.C.S., and Arthur H. Church, F.C.S. Post 8vo, 10*s.* 6*d.*

HANDBOOK OF CHEMICAL MANIPULATION. By C. Greville Williams. 15*s.*

ELEMENTARY COURSE OF GEOLOGY, MINERALOGY, AND PHYSICAL GEOGRAPHY. By David T. Ansted, M.A. &c. Second Edition, 12*s.*

ELEMENTARY COURSE OF BOTANY: Structural, Physiological, and Systematic. By Arthur Henfrey. 12*s.* 6*d.*

MANUAL OF BRITISH BOTANY. By C. C. Babington, M.A. &c. Fourth Edition, 10*s.* 6*d.*

GENERAL OUTLINE OF THE ORGANIZATION OF THE ANIMAL KINGDOM, by Professor T. Rymer Jones. 8vo, Second Edition, £1 11*s.* 6*d.*

INDEX.